IN TWO SECTIONS—SECTION TWO

# TRANSACTIONS

### of The American Society of Mechanical Engineers

## SOCIETY RECORDS—Part III

### (Including Indexes to Publications)

[*Part I of Society Records for the year 1935 (containing Council and Committee Personnel and other general information) was issued as Section Two of the Transactions for February, 1935, and Part II (Memorial Notices), August, 1935.*]



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# TRANSACTIONS

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# Annual Report of the Council

DURING the past year Society activities were on a substantially better basis than in 1933–1934. Rigorous economy has been observed and it is believed real progress has been made. For the first time in three years the Society income at the end of the first six-months' period was greater than estimated and it was possible to make some increase in appropriations at that time. The financial report for the year will show a modest addition to surplus and a reduction in the debt.

### Information About Members

The improved financial status of the Society enabled the Council and its Executive Committee to give more thought to the interests of the individual members. As a first step, a professional-data form was circulated during the spring, on which members were asked to record their experience and special qualifications. The analysis of these forms is about 60 per cent complete at the close of the fiscal year. Approximately 7000 members returned data and the information will be valuable in formulating programs for publications and activities to meet the general interests of the members. We have up-to-date records of 7000 members that will enable us to give aid to those employers seeking men with unusual experience and qualifications. We also have an accurate record of 860 consulting engineers, showing their detailed specialties, from which to answer inquiries for men qualified to handle specific problems. About 750 members have volunteered for service on committees.

### Improving the Profession

The enhancement of the status of the engineer is the stated purpose of the Engineer's Council for Professional Development in which the A.S.M.E. is participating. The Engineers' Council has made splendid progress in its program of accrediting engineering schools and, as the fiscal year draws to a close, plans are under way to examine some twenty schools in the New England and Middle Atlantic areas. These two areas were chosen for the first trial of accrediting and the development of the scheme will depend upon its success in this experimental area. The Engineers' Council has also promulgated two programs in which the Society is called upon to participate actively through its sections.

(1) The guidance of young men planning to enter engineering as a career.

(2) Stimulation of a self-development program for young men who have been graduated from engineering schools and are preparing themselves to become full-fledged engineers and for those young men who have not had the advantage of a formal education.

Plans for both of these programs have been prepared and communicated to the Sections. The successful execution of these plans provides a direct problem for each Section.

### Registration

During the past year the Council has given a great deal of consideration to the movement looking to the establishment of registration laws for engineers throughout the United States. As the year closes, thirty-five states have such laws.

In June the Council adopted an important policy in this matter as follows:

(1) The A.S.M.E. will present the broad aspects of registration to its members in those states not having registration and stimulate its consideration by them.

(2) The A.S.M.E. will not publicly urge registration in those states where the movement has not taken definite shape.

(3) In those states where a registration movement has been initiated which has the support of representative members, the A.S.M.E., through its members in those states, will offer to support the movement by helping to organize it further, by assisting to formulate a proper legislative bill, by soliciting the support of other engineering societies and outstanding members, by advising appropriate strategy, and by other suitable and proper means.

(4) In those states where registration laws have been enacted, the A.S.M.E., through its members, will encourage (a) amendment of the registration laws for the purpose of improving and making them more uniform, and (b) stricter enforcement of those laws.

At the close of the year Council was giving consideration to the steps necessary to carry out this policy.

### American Engineering Council

The American Engineering Council has completed a good year. Its report appears in detail on another page and is well worth painstaking study. The American Engineering Council has made substantial progress in relating itself to government agencies on engineering matters and has initiated a series of contacts looking to the placement of engineers in government services. It has been instrumental in initiating a special census of engineers, with particular reference to educational background, occupation, income, and present status of employment. Over 50,000 records of individuals are in the hands of the Bureau of Labor Statistics of the U. S. Department of Labor and it is expected that the report will be available about the end of the calendar year.

### Junior Activity

One of the important problems pressing for early solution is the assimilation into the Society activities of the large number of graduates of engineering schools. The program of post-graduate training planned by the E.C.P.D. previously mentioned offers an excellent opportunity for the Society to take an important position of leadership. During the past year a special committee on junior participation was appointed, which has made some valuable suggestions for junior activity. Many sections have adopted active programs for junior participation, but there is still a great opportunity for future developments in this program.

### Changes in Membership Grades

An important change in the membership structure was initiated during the year. As a result of discussions in the E.C.P.D. and in the Committee on Policies and Budget, a revised plan of membership grades was advanced and, after acceptance by the members in meeting at Cincinnati in June, 1935, was submitted to letter ballot. The plan abolishes the present Associate-Member grade, makes some changes in the requirements for a new grade of Member, and adds the Student Member, and the Fellow, the latter being the engineer of distinction.

### General Activities

The meetings of the Society during 1934–1935 were generally satisfactory. The plan of having annually a Calvin W. Rice Memorial Lecture was initiated at the Cincinnati meeting by Dr. Adolph Meyer, of Zurich, Switzerland.

The increase in income from advertising enabled the Council to provide more money for publications during the latter part of the fiscal year. The *Journal of Applied Mechanics* was issued with some assistance in financing from universities, companies,

CHANGES IN MEMBERSHIP, OCTOBER 1, 1934, TO SEPTEMBER 30, 1935

| | Membership | | |
|---|---|---|---|
| | Oct. 1, 1935 | Oct. 1, 1934 | Net Changes |
| Honorary Members..... | 16 | 17 | —1 |
| Life Members.......... | 67 | 67 | 0 |
| Members............... | 6375 | 6548 | —173 |
| Associates............. | 268 | 293 | —25 |
| Associate-Members...... | 2604 | 2658 | —54 |
| Juniors (10)............ | 1448 | 1497 | —49 |
| Juniors (20)............ | 3239 | 3147 | +92 |
| | 14,017 | 14,227 | —210 |

and individuals. The publication problem is, however, a major one and at the close of the fiscal year is being given intensive study by the Publication Committee, the Professional Divisions, the Advisory Board on Technology, and the Council.

With appropriations less than customary two years ago, the operation of Sections was carried on with reasonable satisfaction. Three hundred and one meetings were reported. A scale of measurement of Section operation has been developed and put into use. By this it is hoped that the work of a Section during any period can be more accurately evaluated. Also it aids the Section officers to gage the results of their administration.

In addition to cooperating in the preparation of programs for sessions at annual and semi-annual meetings, the Professional Divisions held five successful national meetings during the year.

This year marked the completion of the installation of the new plan of student branch operation. The number of members in student branches reached a total of 3250. Ten student meetings were held with splendid success.

The Committee on Awards has completed a new scheme for administering the honors and awards for the Society, by which a Board of Honor and a Medal Committee will be established. Revisions of the By Laws are under consideration by the Council at the close of this fiscal year.

The technical committee work of the Society was carried on with unexpected activity in view of the condition of the times. Nineteen of the twenty-four research committees showed substantial progress. Ten standards were completed and presented to the American Standards Association for approval. One new Power Test Code and one revised code were published and two new sections and one revised section of one of the codes were completed and approved by the Council.

During the year progress was made in improving contact between the members of the Council and the members of the Society at large. In addition, the President and Secretary visited 48 Sections and 34 Student Branches.

The financial report indicates that the Society has operated well within its income, and has reduced its indebtedness materially.

### Advisory Boards

This year saw the initiation of three advisory boards, formed to coordinate the functioning of certain related committees: The Advisory Board on Technology is concerned with meetings, divisions, research, and publications; the Advisory Board on Standards and Codes is concerned with the boiler code, standardization, power test codes, and safety; the Advisory Board on Professional Status is concerned with membership, registration, and the E.C.P.D. These boards made up of representatives of committees with a chairman designated from the Council and set up on an experimental basis for two years, have started to function and have made substantial progress.

### Reports of Committees

The complete reports of the standing and special committees follow. They are worthy of painstaking study.

### The Parker Case

Shortly before the opening of the fiscal year, Mr. John C. Parker brought action in the Supreme Court looking to an investigation of Society activities, particularly in connection with the Engineering Index and the Boiler Code. The investigation was started in April and continued intermittently through the rest of the year. It is expected that the report of the investigation will be completed before the Annual Meeting. Upon its completion, the Council will render a complete report to the membership.

C. E. Davies, *Secretary*

# Reports of Standing and Special Committees

## FINANCE

For the second consecutive year since the effects of the depression in the fall of 1931 began to be reflected in its financial affairs, the Society has lived within its income.

(*A*) Yearly Operating Results based upon inclusion of initiation fees:

| | 1931–32 | 1932–33 | 1933–34 | 1934–35 |
|---|---|---|---|---|
| Total Income | $576,590.14 | $409,729.73 | $395,642.53 | $383,830.05 |
| Total Expense and Charges | 644,588.52 | 441,281.86 | 354,936.56 | 362,905.06 |
| Net Income or Deficit for the Year | $ 67,998.38 (deficit) | $ 31,552.13 (deficit) | $ 40,705.97 (net income) | $20,924.99 (net income) |

(*B*) Yearly Operating Results based upon exclusion of initiation fees:

| | 1931–32 | 1932–33 | 1933–34 | 1934–35 |
|---|---|---|---|---|
| Total Income | $560,301.81 | $396,934.29 | $380,287.93 | $368,029.82 |
| Total Expense and Charges | 644,588.52 | 441,281.86 | 354,936.56 | $362,905.06 |
| Net Income or Deficit for the Year | $ 84,286.71 (deficit) | $ 44,347.57 (deficit) | $ 25,351.37 (net income) | $ 5,124.76 (net income) |

The Finance Committee considers this accomplishment an encouraging indication that the financial condition of the Society is improving. The actual total income during the past year is 6 per cent greater than the budgeted estimate. The situation with respect to dues is considerably better than it was a year ago. For the past two years there has been a slow, but steady increase in the revenue received from advertising and sale of publications. The earnings from investments have continued to hold at an average of approximately 4 per cent. The financial position of the Society, as reflected by its balance sheet, is increasingly liquid. Questionable assets have been written down to amounts believed to be conservative; the current liabilities have been reduced. If these improvements may be considered as indicative, it would seem that a critical period in the history of the Society has been successfully passed.

### Statements

In accordance with the practice of recent years, this annual report of the Finance Committee, for the fiscal year ended September 30, 1935, includes detailed comparative statements of the Society's operations for the past two fiscal years. A brief explanation of the statements may assist the membership and committees in a clearer understanding of what the Finance Committee has set forth.

The summary of expanses given in the income and expense statement in Exhibit A is supported by detailed statements, viz.: direct appropriations to Standing Committees of Council in Schedule 1; printing and distribution expenses of publications in Schedule 2; and the itemized expenses of operating the office of the Society in Schedule 3. Additional schedules are included for those members who prefer to have the expenses shown differently, as follows: the departmental expenses of the office are shown in Schedule 4, with the explanation of the activities carried on by each department; in Schedule 5 is given the total cost of the many activities of the Society, obtained by adding to the direct appropriation for each activity its proportionate share of the office expense; finally, the total cost of Society activities is summarized into major groups of services in Schedule 6. The accompanying chart of income and expenditures per member is based upon the total income, including initiation fees, as given in the first column of Exhibit A and upon total expenses and charges as given in the first column of Schedule 6.

The amount collected from initiation fees was not used for operating expenses, but was put directly into surplus as shown in Exhibit A. The net income for the year shown at the bottom of Exhibit A was, likewise, added to surplus. It represents the difference between all income, except that from initiation fees, and total expenses and charges. These additions to surplus, together with other entries directly affecting surplus, are shown in Exhibit B. The balance in the surplus account on September 30, 1935, is the difference between the total assets and the total liabilities of the Society on that date and is so shown in the balance sheet, Exhibit C, before providing for decline from the purchase price to the present quoted market value of the Society's investments, exclusive of trust-fund investments.

The annual audit of the Society's accounts for the fiscal year ended September 30, 1935, has again been made by Messrs. Haskins & Sells, Certified Public Accountants. As explained in the notation following this report, Exhibits A, B, and C and Schedules 1 and 3 were prepared from the auditor's report, whereas, the statements Schedules 2, 4, 5, and 6 were prepared from the Society's records. The statements from the two sources are in entire agreement.

### Financial Management

Evidence of the efforts made by the Council to improve the financial position of the Society is apparent from the following: (*a*) insistence upon strict adherence to the budget, (*b*) write-offs of uncertain assets, (*c*) wipe-off of deferred charges, (*d*) facing the facts about present market values of securities, (*e*) reduction of the bank debt, (*f*) advantageous disposal of marketable securities, (*g*) constant attention to the Society's investments, (*h*) unremitting study of trust-fund and other fund requirements, and (*i*) judicious formulation of future policies.

### Budget Adherence

Some of the major budget policies formulated by Council in June, 1934, which have been strictly adhered to are: (*a*) the amount available for budget appropriations for Society expenses not to exceed 95 per cent of the estimated gross income, (*b*) an amount equal to the income received from initiation fees to be appropriated from surplus for the reduction of the bank debt, (*c*) efforts to be made to reduce the bank debt by the advantageous sale of securities as opportunity arose, (*d*) no new activity to be undertaken unless definitely known that the funds required would be available without decreasing appropriations or existing essential activities.

### Recent Write-Offs

Upon recommendation of the Finance Committee, after careful consideration, Council has approved many drastic write-offs of uncertain assets and deferred charges during the past four years, in order to present more accurately the Society's condition. An examination of the surplus statements and balance sheets for September 30, 1932, 1933, 1934, and 1935 shows the following major write-offs or creation of reserves:

| | | |
|---|---|---|
| 1932, Dues | $ 55,000.00 | |
| Deferred deficits of Engineering Index from Oct. 1, 1927, to Sept. 30, 1931 | 81,740.99 | $136,740.99 |
| 1933, Dues | $164,317.89 | |
| Advertising account | 20,384.69 | |
| Obsolete and inactive items in inventory | 78,660.48 | $263,363.06 |
| 1934, Dues | $120,448.65 | |
| Revaluation of Engineering Index inventory and transfer of receivables to Engineering Index, Inc. | 34,217.78 | |
| Deferred charge for fiftieth anniversary | 24,399.66 | |
| Adjustment in publication inventory | 10,098.19 | $189,164.28 |
| 1935, Dues | | $ 10,000.00 |

### Dues Situation

After a three-year adherence to a lenient dues-payment policy, the Council deemed it necessary in 1934 to begin clarifying the membership status by dropping or suspending, on September 30, 1934, those members who on that date owed dues for two full years or more. Further analysis of the dues accounts in 1935 resulted in the dropping of additional members on June 18, 1935. Although the actual write-offs of the unpaid dues of these members did not take place until the current fiscal year, provision therefore was made out of income in the years shown below:

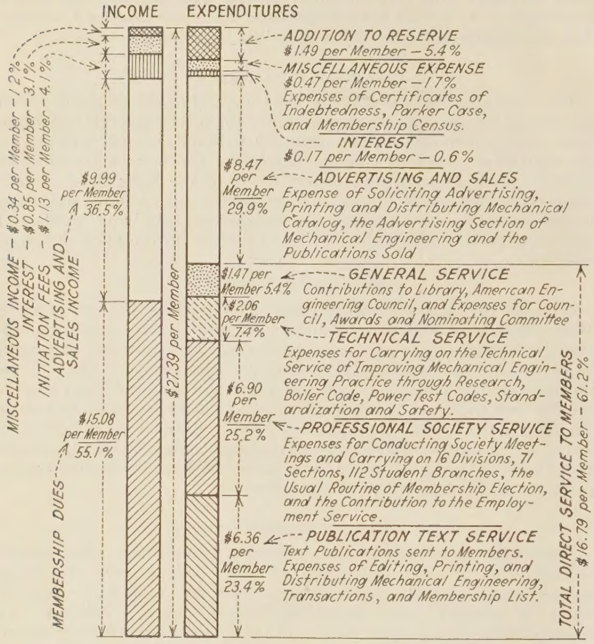
| | |
|---|---|
| Year ended September 30, 1932 | $ 55,000.00 |
| Year ended September 30, 1933 | 164,317.89 |
| Year ended September 30, 1934 | 120,448.65 |

The sum of these three charges when added to the corresponding expense of $10,000.00 for the present fiscal year, makes the total provision for uncollectible dues for the entire four-year period ended September 30, 1935, $349,766.54.

As the result of the foregoing write-offs and creation of reserves, the amount of dues receivable shown on the balance sheet, Exhibit C, is considered to be collectible in its entirety.

Furthermore, a most favorable dues situation has resulted from the efforts of Council to clarify the membership status. This is

A.S.M.E. INCOME AND EXPENDITURES PER MEMBER, 1934-35




apparent from the fact that, despite a 30-per cent shrinkage in the membership during the past year, the cash collections of dues were improved, as shown:

Year ended September 30, 1934.....$199,868.73
Year ended September 30, 1935..... 201,967.21

### Current Condition

On the basis of quoted market values of investments, the current condition of the Society is more liquid than it was a year ago, as shown by the ratio of current assets to current liabilities:

At September 30, 1934......1.3
At September 30, 1935......1.9

This corresponds with an increase in the net working capital, or excess of current assets over current liabilities of:

| | Current Assets | Current Liabilities | Net Working Capital |
|---|---|---|---|
| At September 30, 1934..... | $154,741.85 | $114,562.88 | $40,178.97 |
| At September 30, 1935..... | 135,289.88 | 74,771.93 | 60,517.93 |

The foregoing ratios and statement of net working capital are computed on the conservative basis used in the Society's balance sheets, and do not take into consideration real estate mortgage bonds and certificates both unpledged and pledged as collateral to bank notes payable having a quoted market value of $71,350.00 at September 30, 1934, and $75,685.00 at September 30, 1935. The reason for the exclusion of these items is their less ready marketability as explained later under the heading "Investments."

### Debt Reduction

The demand note held by the bank has been steadily reduced as shown below:

| | Amount of Note | Yearly Reductions |
|---|---|---|
| September 30, 1933............... | $164,000.00 | |
| September 30, 1934............... | 57,500.00...... | $106,500.00 |
| September 30, 1935............... | 17,000.00...... | 40,500.00 |

The reduction has been accomplished by the application of funds received from three sources:

| | 1933–34 | 1934–35 |
|---|---|---|
| Current income ..................... | $ 8,897.36 | $13,951.93 |
| Sale of securities .................... | 61,287.42 | 17,713.29 |
| Sale of certificates of indebtedness to members...................... | 36,315.22 | 8,834.78 |
| Total reduction in bank debt......... | $106,500.00 | $40,500.00 |

### Sale of Securities

By close observation of the daily market quotations of the issues of railroad and public-utility bonds owned by the Society, the Finance Committee, upon authority of Council, was able to sell certain securities from the Society's portfolio at a profit and thereby to reduce the bank loan. The face value, cost, and net selling price of the securities sold during the past two years are given in the accompanying Table 1.

TABLE 1

| (A) Securities sold during 1933–34 | Face Value | Cost | Net Selling Price |
|---|---|---|---|
| Binghamton Light, Heat and Power Co. 5%, 1946.................... | $ 5,000.00 | $ 5,000.00 | $ 4,931.62 |
| Central Maine Power Co. 5%, Series D, 1955........................ | 10,000.00 | 10,100.00 | 9,974.37 |
| Commonwealth Edison Co. 5%, 1935 | 5,000.00 | 5,118.75 | 5,194.50 |
| Cumberland County Power & Light Co. 4½%, 1959.................. | 2,000.00 | 1,890.00 | 1,877.95 |
| Dallas Power & Light Co. 5%, Series C, 1952........................ | 5,000.00 | 5,000.00 | 5,184.87 |
| Metropolitan Edison Co. 5%, Series C, 1953........................ | 5,000.00 | 5,012.50 | 5,036.12 |
| New York Central and Hudson River Railroad Co. debenture 4%, 1942. | 25,000.00 | 23,062.50 | 23,943.12 |
| San Diego Consolidated Gas and Electric Co. 5%, Series B, 1947..... | 5,000.00 | 5,075.00 | 5,144.87 |
| Total during 1933–34.......... | $62,000.00 | $60,258.75 | $61,287.42 |
| (B) Securities sold during 1934–35 | | | |
| Alabama Power Co. 5%, 1951...... | $ 5,000.00 | $ 5,000.00 | $ 4,831.90 |
| Cumberland County Power & Light Co. 4½%, 1959.................. | 3,000.00 | 2,835.00 | 2,816.86 |
| Public Service Company of Northern Illinois 5%, 1966................ | 5,000.00 | 4,962.50 | 5,107.26 |
| Texas Power & Light Co. 5%, 1956... | 5,000.00 | 4,850.00 | 4,957.27 |
| Total during 1934–35........... | $18,000.00 | $17,647.50 | $17,713.29 |

### Sale of Certificates of Indebtedness

On March 21, 1934, the Council authorized an aggregate issue of $125,000.00 of four per cent Certificates of Indebtedness, due January 1, 1936, to January 1, 1944, to be sold to the membership of the Society. Between that date and September 30, 1934, certificates amounting to $36,450.00 were purchased by members. In the current year additional certificates amounting to $8,700.00 have been purchased by members, thus bringing the amount issued to $45,150.00 on September 30, 1935. Of this amount $600.00 face value of certificates have been donated to the Society by members and are held in the treasury. Those members who purchased Certificates of Indebtedness are to be commended for their willingness to assist the Society. By their loyal support they have not only enabled the Society to reduce its indebtedness to the bank and to lower the annual interest rate by one per cent from the former level; but, in instances where purchased certificates have been donated to the Society, those members have beneficently opened a new channel of revenue through which the Society's financial condition may now be continuingly strengthened.

### Investments

The status of each real-estate mortgage bond and certificate has been analyzed and studied. With the exception of two mortgage bonds with a combined face value of $54,000.00, all mortgage bonds and certificates owned by the Society, whether as investments or as trust-fund securities, are issues of the Lawyers Mortgage Company. Practically all mortgage bonds of the Society are secured by real-estate properties in New York City. The Department of Insurance and the Mortgage Commission of the State of New York have endeavored to rehabilitate the Lawyers' Mortgage Company by supervising its operations during the depression. The quoted market value for real-estate mortgages in New York City is low, inasmuch as investors are not buying that form of security; but the majority of the properties

in which the Society has a participating interest are being well managed. This is evidenced by the average yield on real-estate mortgage bonds and certificates owned by the Society which was:

| | Trust-Fund Investments | Other Investments | Average |
|---|---|---|---|
| For Fiscal year: 1933-34 | 4.46% | 3.37% | 3.64% |
| 1934–35 | 4.13% | 3.59% | 3.75% |

Although the average yield is exceptionally good for this class of investment at the present time, the mortgages are still in a "distress market." In most cases the market value of these investments is expected ultimately to return to nearly the original purchase price.

The complete schedule of securities owned by the Society appeared in the annual report of Council for 1932–1933 on page 25 of the Record and Index Section of Transactions for 1933. A schedule of securities as of September 30, 1935, has not been included in this report inasmuch as the only changes are those previously noted under the heading "Sale of Securities."

Respectfully submitted,

Walter Rautenstrauch, *Chairman*
Wm. T. Conlon
W. D. Ennis
Wm. H. Gesell
K. M. Irwin
Erik Oberg, *Treasurer*
Ely C. Hutchinson, James H. Herron — *Council Representatives*

### Accountants' Certificate

The American Society of Mechanical Engineers:

We have made an examination of your accounts for the year ended September 30, 1935. Under the terms of our engagement, the accounts receivable, other than advertising accounts, at September 30, 1935, and collections during the year were not verified by confirmations obtained from the debtors, nor were the quantities of the inventories verified by us.

In accordance with recommendations made by us in previous years, the Society during the year under review has compiled detailed records of dues receivable from members. This compilation shows balances receivable at September 30, 1935, aggregating approximately $21,000.00 in excess of the amount shown by the general records. No effect has been given in the accompanying statements to any part of such excess, and therefore the income of the Society for the year under review is conservatively stated. A study now being made by us in conjunction with the Society's staff indicates that a substantial part of the above-mentioned excess has its origin in actions taken by the Society to continue in membership certain individuals whom it had previously expected to drop from the rolls. A supplemental report will be issued setting forth the extent to which the surplus will be adjusted during the fiscal year beginning October 1, 1935, on account of the foregoing.

In conformity with the practice followed by the Society, there have not been included in its accounts nor in the accompanying statements any accruals of interest receivable or payable other than on outstanding certificates of indebtedness.

In our opinion, subject to the foregoing and to the notations on the accompanying statements, the attached balance sheet and statements of income and expenses and of surplus set forth, respectively, your financial condition at September 30, 1935, and the results of your operations for the year ended that date.

(Signed) Haskins & Sells

New York
November 30, 1935

Note: The following Exhibits A, B, and C and Schedules 1 and 3 have been prepared from the report of Messrs. Haskins & Sells; Schedules 2, 4, 5, and 6 have been prepared by the Finance Committee from the Society's records.

## EXHIBIT A

## COMPARATIVE STATEMENT OF INCOME AND EXPENSES

### For Two Fiscal Years Ended September 30, 1935

| Income | 1934–35 | 1933–34 |
|---|---|---|
| Initiation fees (carried to Surplus)—See Exhibit B | $ 15,800.23 | $ 15,354.60 |
| Membership dues (Less provision for dues considered uncollectible at September 30, 1935, $10,000.00; September 30, 1934, $120,448.65) | $201,660.34 | $198,731.15 |
| Student dues | 9,738.50 | 6,781.35 |
| Interest and discount | 11,871.06 | 13,883.15 |
| *Mechanical Engineering* advertising | 53,503.64 | 49,195.37 |
| Mechanical Catalog advertising | 42,258.15 | 41,156.63 |
| Publication sales | 47,712.06 | 39,522.83 |
| Miscellaneous sales | 1,440.25 | 1,486.59 |
| *Journal of Applied Mechanics* contributions | 1,531.00 | |
| Engineering Index | | 25,715.18 |
| Contributions unrestricted | 23.00 | 982.06 |
| Technical Committee contributions | 400.00 | 1,577.28 |
| | $370,138.00 | $379,031.59 |
| Less: Provision for and write-offs of accounts receivable other than dues, and adjustment of controlling account, less recoveries | 3,466.97 | 3,972.33 |
| | $366,671.03 | $375,059.26 |
| Authorized transfer from Trust Funds | | 4,200.00 |
| Net profit on securities sold | 65.79 | 1,028.67 |
| Sales of equipment | 1,293.00 | |
| Total Income | $368,029.82 | $380,287.93 |
| **Expenses and Charges** | | |
| Committee expense—See Schedule 1 | $ 59,687.04 | $ 50,893.96 |
| Publications expense—See Schedule 2 | 103,535.63 | 85,625.30 |
| Office expense—See Schedules 3 and 4 | 190,703.57 | 188,129.88 |
| Engineering-Index expense | | 21,235.20 |
| Certificates-of-Indebtedness—interest and issuing expense | 1,895.18 | 1,047.64 |
| *Journal of Applied Mechanics*—Editorial Board expense | 285.43 | |
| Parker Case expenses paid to date | 2,326.37 | |
| Membership census | 2,054.66 | |
| Total Expenses—See Schedules 5 and 6 | $360,487.88 | $346,931.98 |
| Interest and discount charges | 2,417.18 | 8,004.58 |
| Total expenses and charges | $362,905.06 | $354,936.56 |
| Net Income for the year (carried to Surplus)—See Exhibit B | $ 5,124.76 | $ 25,351.37 |

### SCHEDULE 1. COMMITTEE EXPENSE

(Direct Appropriation Only)

| | 1934–35 | 1933-34 |
|---|---|---|
| Council | $ 2,560.98 | $ 3,521.23 |
| Engineering Societies Library | 8,509.53 | 8,193.71 |
| American Engineering Council | 8,778.00 | 6,055.00 |
| Sections Committee—mileage | 853.10 | 552.18 |
| Sections Delegates—mileage | 1,716.74 | 3,214.69 |
| Sections operation | 13,690.55 | 9,761.43 |
| Awards | 364.38 | 394.03 |
| Nominating Committee | 416.06 | 740.11 |
| Relations with Colleges—mileage | 74.95 | 110.47 |
| Research (Grants to Initiate Projects) | | 208.00 |
| American Standards Association | 500.04 | 625.01 |
| Divisions Meetings | 2,781.52 | 2,444.63 |
| Society's Meetings | 4,822.90 | 4,333.47 |
| Engineering Societies Employment Service | 8,240.27 | 6,923.58 |
| Student-Branches Operation | 6,378.02 | 3,816.42 |
| Total | $ 59,687.04 | $ 50,893.96 |

### SCHEDULE 2. PUBLICATIONS EXPENSE

(Printing and Distribution Only)

| | 1934–35 | 1933–34 |
|---|---|---|
| *Mechanical Engineering* Text Pages | $ 24,950.48 | $ 22,769.94 |
| Membership List | 3,869.29 | |
| Transactions | 22,849.96 | 21,358.69 |
| *Journal of Applied Mechanics* | 3,929.75 | |
| *Mechanical Engineering* Advertising Pages | 11,205.49 | 9,616.57 |
| Mechanical Catalog | 16,927.92 | 15,709.09 |
| Other Publications Sold | 19,802.74 | 16,171.01 |
| Total | $103,535.63 | $ 85,625.30 |

## SCHEDULE 3. OFFICE EXPENSE

(Classified by Items)

| | 1934–35 | 1933–34 |
|---|---|---|
| Salaries | $143,201.78 | $146,424.05 |
| Commissions | 2,323.99 | 1,583.30 |
| Postage | 8,040.75 | 7,650.45 |
| Printed matter | 5,827.53 | 5,223.79 |
| Publicity | 541.55 | |
| Traveling | 5,967.34 | 3,679.83 |
| Collections | 197.10 | 145.42 |
| Telephone and telegraph | 4,187.40 | 4,151.03 |
| Insurance | 991.16 | 1,149.27 |
| Office Supplies | 4,446.91 | 3,399.17 |
| Secretary's Emergency Fund | 257.82 | 50.00 |
| Rent | 7,270.58 | 8,509.83 |
| Stationery | 1,658.81 | 1,151.27 |
| Maintenance and repair | 706.78 | 455.10 |
| Cost of Miscellaneous sales | 955.39 | 935.19 |
| Depreciation of furniture and equipment | 1,300.00 | 1,300.00 |
| Unclassified | 3,058.93 | 2,588.37 |
| | $190,933.82 | $188,396.07 |
| Less Receipts | 230.25 | 266.19 |
| TOTAL | $190,703.57 | $188,129.88 |

## SCHEDULE 4. OFFICE EXPENSE

(Classified by Departments)

| | Salary expense | Other expense[a] | Total Expense 1934–35 | Total Expense 1933–34 |
|---|---|---|---|---|
| General Department: General supervision, staff service to Council, Executive Committee, Special Committees of Council, Committees on Finance and Publications, central accounting, purchasing, stores, addressograph, duplicating, files, clerical and stenographic | $50,448.02 | $15,445.49 | $65,893.51 | $65,823.02 |
| Field Department: Staff service for Sections, Branches, Meetings, Divisions, Membership, Awards, Employment Service, Chicago and Tulsa Offices | 28,293.33 | 6,868.40 | 35,161.73 | 32,969.24 |
| Technical Department: Staff service for Committees on Boiler Code, Power Test Codes, Research, Safety and Standardization | 14,782.32 | 2,107.46 | 16,889.78 | 18,896.05 |
| Editorial Department | 19,210.41 | 1,036.69 | 20,247.10 | 20,913.77 |
| Advertising Department | 24,888.38 | 9,116.76 | 34,005.14 | 31,436.90 |
| Publication Sales Department | 5,579.32 | 3,365.25 | 8,944.57 | 7,131.80 |
| Rent, Insurance, Depreciation | ....... | ....... | 9,561.74 | 10,959.10 |
| TOTAL | $143,201.78 | $37,940.05 | $190.703.57 | $188,129.88 |

[a] Other expense includes postage, printed matter, travel, telephone and telegraph, office supplies, stationery, maintenance and repair, and unclassified.

## SCHEDULE 5. DETAILED COST OF A.S.M.E. ACTIVITIES

| Activities | Committee Expense | Printing and Distribution Expense | Office Expense | Total Cost 1934–35 | Total Cost 1933–34 |
|---|---|---|---|---|---|
| Council (President; Executive Committee) | $ 2,560.98 | ....... | ....... | $ 2,560.98 | $ 3,521.23 |
| *Standing Committees of Council* | | | | | |
| Awards | 364.38 | ....... | ....... | 364.38 | 394.03 |
| Library | 8,509.53 | ....... | ....... | 8,509.53 | 8,193.71 |
| Local Sections | 16,260.39 | ....... | $18,418.14 | 34,678.53 | 31,022.89 |
| Operation | (13,690.55) | ....... | ....... | ....... | ....... |
| Delegates Conference | ( 1,716.74) | ....... | ....... | ....... | ....... |
| Committee Mileage | ( 853.10) | ....... | ....... | ....... | ....... |
| Meetings and Program | 4,822.90 | ....... | 7,619.52 | 12,442.42 | 11,188.20 |
| Membership | | | | | |
| Applications | ....... | ....... | 5,936.54 | 5,936.54 | 5,218.74 |
| Development | ....... | ....... | 5,936.55 | 5,936.55 | 5,218.74 |
| Power Test Codes | ....... | ....... | 4,274.00 | 4,274.00 | 7,356.22 |
| Professional Divisions | 2,781.52 | ....... | 7,619.51 | 10,401.03 | 9,299.36 |
| Publications | | | | | |
| Engineering Index | ....... | ....... | ....... | ....... | 21,235.20 |
| *Journal of Applied Mechanics* | ( 285.43) | $ 3,929.75 | 2,215.78 | 6,430.96 | ....... |
| Mechanical Catalog | ....... | 16,927.92 | 25,203.91 | 42,131.83 | 39,372.40 |
| *Mechanical Engineering* Advertising Pages | ....... | 11,205.49 | 30,951.23 | 42,156.72 | 39,030.16 |
| *Mechanical Engineering* Text Pages | ....... | 24,950.48 | 18,119.95 | 43,070.43 | 42,943.80 |
| Membership List | ....... | 3,869.29 | 667.75 | 4,537.04 | ....... |
| Publications for sale | ....... | 19,802.74 | 14,749.82 | 34,552.56 | 28,214.93 |
| Transactions | ....... | 22,849.96 | 12,443.62 | 35,293.58 | 36,498.60 |
| Relations With Colleges (Student Branches) | 6,452.97 | ....... | 11,076.45 | 17,529.42 | 13,647.01 |
| Operation | ( 6,378.02) | ....... | ....... | ....... | ....... |
| Committee Mileage | ( 74.95) | ....... | ....... | ....... | ....... |
| Research | ....... | ....... | 7,772.09 | 7,772.09 | 7,929.76 |
| Technical Inquiries | ....... | ....... | 877.51 | 877.51 | 843.75 |
| Safety | ....... | ....... | 2,676.09 | 2,676.09 | 2,641.05 |
| Standardization | ....... | ....... | 6,674.09 | 6,674.09 | 9,290.88 |
| *Special Committees of Council* | | | | | |
| Boiler Code | ....... | ....... | 6,593.51 | 6.593.51 | 5,086.14 |
| Certificates of Indebtedness | ....... | ....... | ....... | 1,895.18 | 1,047.64 |
| Membership Census | ....... | ....... | ....... | 2,054.66 | ....... |
| Nominating Committee | 416.06 | ....... | ....... | 416.06 | 740.11 |
| Parker Case | ....... | ....... | ....... | 2,326.37 | ....... |
| *Joint Activities* | | | | | |
| American Engineering Council | 8,778.00 | ....... | ....... | 8,778.00 | 6,055.00 |
| American Standards Association | 500.04 | ....... | ....... | 500.04 | 625.01 |
| Engineering Societies Employment Service | 8,240.27 | ....... | 877.51 | 9,117.78 | 10,317.42 |
| GRAND TOTAL | $59,687.04 | $103,535.63 | $190,703.57 | $360,487.88 | $346,931.98 |

SCHEDULE 6. TOTAL COST OF A.S.M.E. ACTIVITIES

| | 1934–35 | 1933–34 |
|---|---|---|
| General Service—Contributions to Library, American Engineering Council, and expense of Council, Awards, and Nominating Committees | $ 20,628.95 | $ 18,904.08 |
| Society Activities—Expenses for Society Meetings, Professional Divisions, Local Sections, Student Branches, Membership Election, and contributions to Employment Service | 96,919.78 | 86,756.11 |
| Technical Service—Expenses of Committees on Boiler Code, Power Test Codes, Research, Safety, and Standardization | 28,489.82 | 32,929.06 |
| Publication Text Service—Expenses of editing, printing, and distributing text section of *Mechanical Engineering*, Transactions, *Journal of Applied Mechanics*, and Membership List | 89,332.01 | 79,442.40[a] |
| Advertising and Sales—Expenses of soliciting advertising, printing, and distributing Mechanical Catalog, Advertising Section of *Mechanical Engineering*, and publications sold | 118,841.11 | 106,617.49 |
| Engineering-Index—Expenses of editing, printing, soliciting, and distributing Card Service and Annual Volumes | | 21,235.20 |
| Certificates of Indebtedness—Expenses of soliciting sales, printing certificates, legal service and interest | 1,895.18 | 1,047.64 |
| Cost of Parker Case—Expenses of legal counsel, minutes of hearings, and printing papers on appeal | 2,326.37 | |
| Membership Census—Expenses of printing, distributing, and analyzing biographical data sheets of members | 2,054.66 | |
| TOTAL | $360,487.88 | $346,931.98 |

[a] No expense of *Journal of Applied Mechanics* nor Membership List in 1933–34.

## EXHIBIT B

## STATEMENT OF SURPLUS

### For Fiscal Year Ended September 30, 1935

| | | |
|---|---|---|
| BALANCE, OCTOBER 1, 1934, PER SOCIETY ANNUAL REPORT | | $222,596.59 |
| CREDITS: | | |
| Initiation Fees | $15,800.23[a] | |
| Adjustment of Prior Years' Interest—Retirement-Fund Reserve | 1,810.46 | |
| Reduction in Capital Investment | 557.56 | |
| Adjustment of Prior Year's Inventory | 115.76 | |
| Net Income for the Year, per Exhibit A | 5,124.76 | 23,408.77 |
| TOTAL | | $246,005.36 |
| CHARGES: | | |
| Write-Off of Loan to Committee on Thermal Properties of Steam | $ 4,000.00 | |
| Assessment by United Engineering Trustees, Inc., for construction of Library stacks in a prior year | 2,500.00 | |
| Reduction of Brashear Biography Inventory value | 457.92 | |
| Adjustment of Custodian-Fund Interest Applicable to prior year | 197.99 | 7,155.91 |
| BALANCE, SEPTEMBER 30, 1935 (representing excess of income, including initiation fees, over operating expenses and other charges, and subject to provision not having been made for decline of $163,200.64, as of September 30, 1935, in the quoted market value of the Society's investments, exclusive of trust-fund investments) | | $238,849.45 |

[a] It being the practice of the Society to take up initiation fees only as and when collected, the above statement does not include such fees receivable at September 30, 1935, and October 1, 1934.

## EXHIBIT C

## BALANCE SHEET, SEPTEMBER 30, 1935

### Assets

| | | | |
|---|---|---|---|
| **Current Assets:** | | | |
| Cash | | $ 17,421.80 | |
| Accounts receivable: | | | |
| Dues (less reserve for uncollectible items, $32,253.17) | $10,295.34 | | |
| Publications and advertising (less reserve for uncollectible items, $4,000.00) | 44,840.61 | | |
| Miscellaneous | 1,232.16 | 56,368.11 | |
| Inventories: | | | |
| Publications for sale | $35,378.54 | | |
| Publications in process | 8,092.49 | | |
| Supplies | 4,741.94 | 48,212.97 | |
| Securities—At cost (quoted market value, $13,287.00)—$23,177.64 deposited as collateral to bank note payable | | 23,277.64 | |
| Total Current Assets | | | $ 145,280.52 |
| **Real-Estate Mortgage Bonds and Certificates**—at Cost (quoted market value, $110,540.00): | | | |
| Pledged as collateral to bank note payable | | $ 86,000.00 | |
| Pledged as collateral to Certificates of Indebtedness | | 68,750.00 | |
| Unpledged | | 109,000.00 | |
| Total Real-Estate Mortgage Bonds and Certificates | | | 263,750.00 |
| **Trust-Fund Assets:** | | | |
| Corporate stocks and real-estate mortgage certificates (quoted market value, $66,370.52) | | $118,127.16 | |
| Cash | | 2,640.44 | |
| Total Trust-Fund Assets | | | 120,767.60 |
| **Property-Fund Investments:** | | | |
| One-fourth interest in real-estate and other assets of United Engineering Trustees, Inc., exclusive of trust funds | | $496,948.48 | |
| Office furniture and fixtures (depreciated value) | | 23,719.60 | |
| Library books | | 1.00 | |
| Engineering Index—Title and good-will | | 1.00 | |
| Total Property-Fund Investments | | | 520,670.08 |
| **Deferred Charges**—Society Activities Applicable to Subsequent Years | | | 141.46 |
| Total | | | $1,050,609.66 |

### Liabilities

| | | | |
|---|---|---|---|
| **Current Liabilities:** | | | |
| Note payable—Bank (See securities pledged, contra) | | $ 17,000.00 | |
| Accounts payable | | 21,382.00 | |
| Unfilled commitments—Estimated liabilities relating to "Mechanical Catalog" for 1935–1936, etc. | | 13,700.20 | |
| Assessment payable—United Engineering Trustees, Inc. | | 2,000.00 | |
| Custodian funds | | 16,243.23 | |
| Reserve for prepaid subscriptions | | 4,000.00 | |
| Accrued interest on certificates of indebtedness | | 446.50 | |
| Total Current Liabilities (exclusive of Certificates of Indebtedness to be redeemed January 1, 1936) | | | $ 74,771.93 |
| **Four Per Cent Certificates of Indebtedness**, Due January 1, 1936, to January 1, 1944 (10% of the total amount issued to be redeemed January 1, 1936)—See investments pledged, contra: | | | |
| Authorized | $125,000.00 | | |
| Issued | | $ 45,150.00 | |
| Less in treasury | | 600.00 | 44,550.00 |
| **Trust-Fund Reserves:** | | | |
| Principal | | $111,120.02 | |
| Income | | 9,647.58 | 120,767.60 |
| **Property Fund Reserve** | | | 520,670.08 |
| **Reserve for Employees' Retirement Allowances** | | | 15,921.61 |
| **Deferred Credit**—Dues Received in Advance | | | 35,078.99 |
| **Surplus** (representing excess of income, including initiation fees, over operating expenses and other charges, and subject to provision not having been made for decline of $163,200.64 as of September 30, 1935, in the quoted market value of the Society's investments, exclusive of trust-fund investments), per Exhibit B | | | 238,849.45 |
| Total | | | $1,050,609.66 |

Notation:

In accordance with the Society's practice, initiation fees receivable are not included in the above statement as they are taken up by the Society as assets only as and when collected.

## MEETINGS AND PROGRAM

With each year there are changes in the aspects of the work of the Committee on Meetings and Program and its problems are constantly shifting. Through it all there remain, however, certain fundamental requirements upon which it is periodically necessary to place pressure that the Society as a whole may continue its progress and provide for the service and welfare of the members.

In the year just concluded the Committee's slogan has been "Better meetings and bigger attendance, within the budget." Necessarily the latter presented limitations. Nevertheless, much has been accomplished and reactions to the work of the Committee from the members in general have been encouraging.

For the purpose of developing greater uniformity of action, a suggested policy for the Society with respect to exhibitions held in conjunction with meetings was prepared by the Committee and submitted to the Board of Technology for consideration.

The Annual Meeting which was held December 3 to 7, 1934, was generally satisfactory. Dr. John H. Finley, editor of the *New York Times* delivered the Calvin W. Rice Memorial Lecture, given to commemorate Dr. Rice's contribution to the development of international friendliness in the engineering profession. Because Dr. Rice's services to the Society were outstanding in international relationships in that field. This memorial should be repeated as occasion is offered, as it was when Dr. Adolph Meyer of Switzerland was the lecturer at the Semi-Annual Meeting at Cincinnati.

At the annual banquet the plan of securing as speaker a well-known and outstanding lecturer upon world affairs was extremely well received. To make it possible for members not attending the banquet to listen to the speaker, it was arranged that for a small entrance fee such members would be admitted to the banquet room. The plan worked moderately well, and it is hoped to develop it further.

At the Annual Meeting a small registration fee was charged for nonmembers who were not invited to attend the Meeting. The plan serves to emphasize the value of the Society to the individual member, and it is hoped to develop it further.

The meeting in Cincinnati was eminently successful in every way. Programs for both meetings were published in the publications of the Society and are to be considered as a part of this report by reference.

The revised pamphlet, "Suggestions to Authors" has resulted in increased excellence of presentation of papers. The policy of printing papers in advance of the meetings has been continued with growing popularity.

Council has allotted for all activities conducted under the supervision of the Meetings and Program Committee for the year 1935–1936 the sum of $5700. This amount will be disbursed by the Committee in such manner as to provide the greatest number of meetings. There are now scheduled the 1935 Annual Meeting to be held in December, 1935, the 1936 Semi-Annual Meeting at Dallas, Texas, as well as regional meetings in San Francisco and Niagara Falls also to be held during 1936.

To enable a larger number of members to enjoy the ceremonies and addresses which have been scheduled heretofore on Tuesday evening of Annual Meeting week, known as "President's Night" it has been decided to transfer some of these events this year to the Banquet night on Wednesday. The President's reception and the Presidential Address will be combined with the Banquet and followed by dancing. Tuesday evening will be designated as "Honors Night" at which time the medals and honors will be presented, to be supplemented by one or two addresses or lectures of importance and current interest.

The committee has studied the general programs of the individual Local Sections and has offered to the officers of the Sections suggestions for improving their programs and aid where suitable speakers could not be found locally. The Committee fostered a policy which will insure publication of Local Section papers that meet the standards required of national meeting papers.

Respectfully submitted,

| | |
|---|---|
| Robert I. Rees, *Chairman* | Clarke Freeman |
| Ely C. Hutchinson | R. F. Gagg |
| Harvey N. Davis | D. C. Cory, *Junior Representative* |

## PUBLICATIONS

At the beginning of the fiscal year the Committee on Publications faced a further decrease in funds below the insufficient amount allotted for publications last year. This forced further curtailment in the services of the committee during the early part of the year, although there was no decrease in the number of papers being presented and recommended for publication. The committee solicited the aid of the Professional Divisions in recommending for publication only papers of outstanding quality and timeliness. The Advisory Board on Technology assisted materially in assenting to a policy for allocating available funds and space among the several technical-paper production agencies of the Society, a plan yet to be worked out in detail, and in urging Council to increase the allotment of funds for publication.

Fortunately an increase in income, both from dues and advertising, enabled the Council to provide more money for publications during the latter part of the fiscal year. Members of the Society expect and are entitled to this direct evidence of an increase in available income. The Committee is continuing to urge the importance of all means for improving the quantity, quality, and timeliness of the technical publications of the Society and for enlarging and improving "Mechanical Engineering."

### Suggestions of Local Sections Delegates

From the Conference of Local Sections Delegates held in connection with the 1934 Annual Meeting the Committee received several suggestions and points of view, all of which were discussed and acted upon.

The confusion existing regarding the name "Record and Index," applied to a publication issued in several sections, only one of which was an index, was cleared up by adopting the name "Society Record" for the sections which are records and "Index" for the final section which is made up of indexes to the Transactions, *Mechanical Engineering*, and miscellaneous publications.

The suggestion that a handbook of codes and standards be distributed free to members was referred to the Advisory Board on Technology.

A suggestion of an assistant editor representing, and resident on, the Pacific Coast was noted but action was withheld for financial reasons.

Comments and suggestions relating to publication policy, requested by the Committee and reported from the individual group conferences were noted and discussed. No serious objections to these policies were registered, but early in 1935 several individuals protested vigorously against the policy of including in *Mechanical Engineering* papers on non-technical subjects, particularly in economic, sociological, and management fields. The Committee attempted to explain its point of view to these critics, and pointed out that in practically every instance the papers on these subjects had been submitted by some official group within the Society, and that the Management Division, whose contributions were objected to on the ground "that they were not engineering," was one of the largest groups in the Society.

For several years the Committee has been alive to criticism of this sort and from time to time has attempted to secure opinions from widely distributed individuals and groups. In the spring of 1935 a "check list" was circulated among selected groups of junior members. One of the objects of this check list was to determine the distribution of reader interest. In all of these attempts to learn what readers want, results have been generally negative. That is, approximately as many do not care for non-technical articles as do. There are very positive statements of preference by some individuals on both sides of this question. It is hoped that the recent census of biographical and professional data will reveal patterns of member interest to guide in selecting material for *Mechanical Engineering*.

### Transactions

During the fiscal year 1934–1935 the Transactions contained 76 papers, a total of 730 pages; these figures include three issues during 1935 of the *Journal of Applied Mechanics*.

In a memorandum to the Council dated July 2, 1934, it was pointed out that with the proposed budget of $18,000 it would be possible to publish only 64 papers. The Council, in noting the memorandum, expressed the opinion that a minimum of 100 papers per year was desirable and put itself on record as wishing to increase the budget for Transactions as soon as conditions would permit so that this number could be attained. While the figure of 64 papers represented a calendar year, the number 76 actually published in the 12 months of the fiscal year shows how closely that desired number may be realized.

During the summer of 1935 eight papers on hydraulic subjects, whose publication had been postponed because of lack of funds, appeared in the Transactions.

Improvement in the Committee's ability to publish papers resulting from meetings is shown in the record of the Cincinnati meeting. Either in *Mechanical Engineering* or the Transactions 32 of the 38 papers for which manuscripts recommended by the sponsoring groups were received either were published or are shortly to be published.

### "Journal of Applied Mechanics"

Under the auspices of the Applied Mechanics Division, a board of editors, headed by John M. Lessells, has been providing material for the section of the Transactions known as the *Journal of Applied Mechanics*. Three issues of the Journal, each of 40 pages, have appeared. The *Journal*, which goes to all members of the Society in good standing, to all subscribers of the Transactions, and to a small list of subscribers to the *Journal* only, has been departmentalized. The departments are: Technical papers; reviews of subject matter within the purview of the Division (to date largely sections of the Division's 1934 Progress Report); design data, a section of material arranged for the immediate use of designers; book reviews; and discussions of papers published in previous issues.

The wealth of available material pressing for publication has proved embarrassing for the editors. At a meeting held in Ann Arbor, Mich., in June, it was decided to limit papers to six pages in order to make possible the publication of a greater number of papers.

Sponsors of the *Journal* are of the opinion that the *Journal* is distributed much more widely than the interest of those who receive it in the subject matter of the papers warrants. They would like to see the circulation reduced to include only those actually desirous of receiving papers of this type. However, a promise was made at the 1933 Annual Meeting to the members of the Society that every member would receive all Transactions papers. This implies that all members shall also receive the *Journal*. The Committee on Publications believes that no change in this policy should be made. In holding this opinion the Committee has in mind not only the 1933 pledge, but the belief that applied mechanics is fundamental to most mechanical-engineering practice. It feels that the wide distribution of all Transactions papers tends to hold the Society's technical interests together, and it recognizes that the great number of younger members, whose careers are still in the formative stage, are better served by "exposure" to a wide range of technical literature than by a too early specialization of interest in what may be, for the individual, a temporary connection with a given field of practice. While the Committee would welcome the voluntary relinquishment of the privilege of receiving the *Journal* by members who have no use for such a publication, it does not wish to be placed in the position of requesting members to give up the *Journal*. Much less would it wish to make every member ask to have the *Journal* sent to him, a request that would not be in keeping with the 1933 pledge.

In order to assist in financing the Journal, its board of editors has solicited funds from interested individuals and organizations. A summary of contributions is as follows:

| | |
|---|---|
| Universities | \$1000.00 |
| Companies | 379.00 |
| Individuals | 157.00 |
| Total | \$1536.00 |

The Committee has no way of estimating how much money can be collected from these sources during the coming year.

The Committee views the *Journal* as being still in the experimental stage, and withholds its comment on the success of the venture. No criticism of the quality of the technical papers is implied nor intended by this statement, and the Committee wishes to record its deep appreciation of the enthusiasm and services to the Society of the Applied Mechanics Division, the board of editors of the Journal, and John M. Lessells, technical editor of the Journal, on whom the burden of providing the material and soliciting the funds has fallen.

### Society Record

Formerly known as the "Record and Index," the present Society Record has been issued from time to time as a supplement to the Transactions. With the February, 1935, issue of Transactions the Society Record contained a complete list of the Society's committee personnel and other reference material as of the administration year that opened in December, 1934. There was thus provided at the earliest practicable moment as complete and up-to-date information on the Society's committees as could be assembled. Heretofore these lists have been of historical interest only as they represented, not the current committee personnel, but that of the previous year.

The scheme of issuing the Society Record in supplements to the Transactions makes it possible to distribute the information contained in the Record as soon as it is available, and also places a more uniform load on the editorial staff. The committee personnel, as already explained, is published as soon as committee appointments have been made; reports of committees are published immediately following the end of the fiscal year and before the Annual Meeting; the indexes to publications appear as soon as the December issues are off the press. Memorial notices of deceased members are issued during the summer.

### Membership List

For the first time since 1931 a membership list was published in December, 1934. It was distributed as a supplement to Transactions for December in order to save postage, and the format was consequently changed.

The Committee feels that the effect on the members of the Society of resuming publication of the Membership List was distinctly favorable and valuable. It was therefore with extreme regret that the Committee noted the vote of the Council at its Cincinnati meeting not to publish the Membership List in 1936. It sustains the hope that early resumption of the membership list as a regular annual publication will be ordered by the Council.

### "Mechanical Engineering"

Plans for the development and improvement of *Mechanical Engineering* still await increase in Society income from dues and advertising, which will permit additions to an overburdened editorial staff. As already noted, the budget for *Mechanical Engineering* was increased during the summer, permitting the continuance of an average of 67 pages per issue, which otherwise would have been cut materially.

The revenue from advertising this year shows an increase over last year's income. It has been understood that any gain should be applied to the publication, and additional funds were made available for publications as already noted. The Committee's financial statement indicates what has been accomplished.

The Committee has received from several sources queries on the relative proportions of subject matter in *Mechanical Engineering*. This led to an analysis covering about 17 issues which showed the following percentages: Technical papers, 54.3 per cent; professional matter, 14.7 per cent; general, 15.5 per cent; and departmental, 15.5 per cent. It also showed the following distribution as to sources from which the material was derived: Meetings and Program Committee, 29 per cent; Professional Divisions, 26 per cent; Local Sections, 11 per cent; Society Committees, 10 per cent; joint activities with other societies, 2 per cent; miscellaneous contributions and staff articles, including "Engineering Progress," 22 per cent.

### Student Branch Bulletin

For eight months during the school year the Student Branch Bulletin, a four-page publication, is distributed with *Mechanical Engineering* to the 3250 members of the Society's 112 student branches.

A hopeful experiment with this publication was inaugurated in September, 1935. A board of editors made up of junior members in the Metropolitan district has taken over the preparation of material for this publication. The following, from the initial issue, explains the objective:

> "The task of editing the 'Student Branch Bulletin' has been taken over by a committee of Junior members of the Society partly to relieve the publications staff, partly to provide an outlet for the energies of younger men, and partly with the hope that the result would be a publication more nearly tuned to the needs and desires of the student engineer."

The Committee wishes to acknowledge its gratitude to this committee and to commend the spirit in which the young men have responded to the opportunity to serve the Society in building up interest among student members.

### Mechanical Catalog

The 1935–1936 edition of the Mechanical Catalog marks the twenty-fifth year of reference service to industry. Improved in makeup, the issue for this year has over 10 per cent more pages of product descriptions than the preceding edition and a new index feature with the title, "Manufacturers' List." The "Classified Index" in the volume has some 4000 product headings, carefully checked as to technical nomenclature.

### Biennial Report

In 1932, under the chairmanship of W. H. Winterrowd, the Committee on Publications made an extensive study of its functions and problems and presented the results to President Lauer in the form of a comprehensive report. Among other recommendations of this report it was suggested that a similar report be prepared every two years. During the spring of 1935 a new report was prepared and presented to the Council at the Cincinnati meeting. At the suggestion of President Flanders the report was assigned for study and discussion at its October meeting.

### Further Study of Publications Policy

Following the presentation of the Biennial Report to the Council the Committee on Publications continued its study of policies at a

meeting on September 6 as a result of more recent developments, among which was a suggestion that the *A.S.M.E. News*, suspended January 1, 1933, be resumed in some form. The Committee's recommendations were presented to the Council at its October meeting.

### Conclusions and Recommendations

As is true of all Society committees, the work of the Committee on Publications has been seriously curtailed during the last few years. It wishes to emphasize the following points:

1 Serious curtailment in funds for publication has had a cumulative and adverse effect on Society prestige and on membership morale. Instances have been cited in annual reports of the committee where other agencies have published papers that should be a part of the Society's literature; of committees and divisions that are discouraged and dissatisfied because papers and reports considered by them to be valuable have not been published by the Society, and of groups that have financed their own publications in impermanent form with the result that they are quickly lost to future researchers in these fields. At the base of most publications problems lies lack of funds.

2 Failure to provide adequate and timely publicity on the Society's activities has resulted in growing disinterest in the Society, ignorance and misunderstanding of what is being accomplished, and a consequent weakening of the morale of members, committees, and divisions. An effective house organ or publicity medium is urgently needed. Whether this should be an independent publication, as was the *A.S.M.E. News*, abandoned for reasons of economy a few years ago, or a development of the news function of *Mechanical Engineering* depends on other questions of publication policy. It is the opinion of the Committee on Publications that the Council should, as soon as possible, make provision for an effective and adequate method of giving publicity to the Society's affairs.

3 The Committee is eager to undertake its long deferred plans for developing and improving *Mechanical Engineering*, and earnestly solicits additional funds for this purpose.

4 Assistance to the Committee's continued study of its problems looking to long-time plans for development and improvement of all its publications is solicited.

Respectfully submitted,

S. W. Dudley, *Chairman*
W. F. Ryan, *Vice-Chairman*
S. F. Voorhees
M. H. Roberts
G. F. Bateman
O. B. Schier, 2d, *Junior Adviser*
A. J. Dickie, E. B. Norris, E. H. Ohle — *Advisory Members*

## LOCAL SECTIONS

The administrative responsibility of the Committee on Local Sections includes matters of finance as well as the correlation and general direction of Local Sections. It acts in a liaison capacity between Sections and Council, Professional Divisions, Research and Standardization Committees, etc., to promote the interest of all. It directs and plans the activities of the Sections and maintains knowledge of these activities by rating, by report, and by personal contact whenever possible.

### General Conditions

Considering the industrial conditions of the country the Local Sections may be considered to be in a satisfactory condition, but they have suffered both from lack of sufficient funds and from loss of membership and leaders.

There is a certain unrest difficult to explain, partially due to inadequate financing in maintaining desired and planned activities, with a consequent lag in interest; partially due to lack of intelligent leadership or initiative on the part of the Section Executive Committees. This, fortunately, is not the case in all Sections. Unrest is fostered by lack of knowledge of Society structure, affairs, and purposes. The members of the Committee on Local Sections have tried by personal contact to advise and educate members in these matters.

The attendance of Sections Delegates both at Group Conferences, and at the Group Delegates' Conference has been a matter of extreme concern to the Committee. The attendance has approximated 60 per cent of that necessary, and nonattendance is due simply to inability of members designated as delegates to attend without serious financial loss to them under the present expense allotment. This is a serious matter to those traveling long distances, and a careful survey indicated that, on the average, every dollar supplied by the Society was matched by a dollar from the pocket of the delegate. This has never been expected nor required, and attendance will not be sufficiently large to permit these conferences to function properly or to voice adequately the advice, desires, and suggestions of the membership unless some method is found to finance completely the delegate's trip.

### Budget, 1935–1936

The Committee regrets that the estimate of Society income was insufficient to allow the amount it requested and considered the minimum necessary for adequate Section operation. Requests for additional funds are frequent. This is a continuing indication of the insufficiency of funds necessary for constructive operation. Dissatisfaction is expressed as to the disbursement of Society funds and is made the excuse for non-payment of dues.

### Group Conferences

Last fall only 53 out of 71 Sections were represented at the Group Conferences. Of these 53, six attended Conferences held in their home cities, therefore only 47 delegates actually traveled to attend. This was the cause of the low expenditure of delegates' mileage, not a commendable saving. Every section is entitled to representation, but that result is secured only when delegates' expenses are fully met.

The superiority and advantages of these Conferences is increasingly evident in better developed agenda, and constructive suggestions to Council. The Committee feels that the work accomplished by these Conferences is most essential.

The Committee approved the following method of electing delegates: "That at each Group Conference Meeting in 1935 two delegates be elected to attend the Delegates' Meeting in New York in December, one delegate to be elected for one year and the other delegate to be elected for two years; and thereafter one delegate shall be elected each year for a term of two years, and be it further provided:

That the Senior Delegate in each Group shall automatically become Chairman of his Group Conference; and it shall be mandatory upon a Local Section to elect such Senior Delegate as its representative to the Group Conference. In such instances the Section will be entitled to another delegate at the Group Conference."

### Redistricting Local Sections

At the suggestion of the Committee on Policies and Budget, the Executive Committee of Council requested the Committee on Local Sections to make a study of the principle of redistricting Local Sections along geographical lines perhaps better suited to the purposes and administration of the Society. The Committee made a complete study of the geographical significance, railroad fares, time of travel, and community of Section interest. Careful inquiry was made of Sections' interests and desires, and several tentative groupings were considered and investigated prior to the Sections Delegates' Conference at Cincinnati.

It was decided from this study by the Committee on Local Sections and the Group Delegates that it would be difficult to develop a better arrangement than that of the present seven groups. Any increase in the number of groups would tend to increase expense, correspondence, postage, travel, exchange of information, details of operation, delay in obtaining action or approval. These are a few of the many factors involved.

### Student Meetings

The Student Meetings held in 1934–1935 were unqualified successes from the standpoints of interest, college and Section cooperation, attendance, and technical papers. It is apparent that the students appreciate the attendance at these Conferences of members of Council, staff, and standing committees. Fortunately it was possible for President Ralph Flanders to attend and address some of the Conferences. This interest shown by the officers of the Society is most impressive to the student. Such contacts are an inspiration to both students and members, and will bear fruitful results. The Committee wishes it were possible for such contacts to be made a permanent policy.

### Schedule and Place of Group Conferences in 1935

| Place | Tentative date | Committeeman to attend |
|---|---|---|
| Group I, Providence | October 26–27 | Ernest Hartford |
| Group II, New York | November 1–2 | Ernest Hartford |
| Group III, Ithaca | October 26–27 | R. E. W. Harrison |
| Group IV, Chattanooga | October 26–27 | W. R. Woolrich |
| Group V, Columbus | October 27–28 | D. B. Prentice |
| Group VI, St. Louis | November 2–3 | D. B. Prentice |
| Group VII, Spokane | November 8–9 | W. L. Dudley |

### Semi-Annual Meeting in 1936

Upon the invitation of E. W. Burbank, Chairman of the North Texas Section, Council scheduled the 1936 Semi-Annual Meeting at Dallas, Texas, to be held during the third week of June.

TABLE 1 SUMMARIZED LOCAL SECTIONS' ACTIVITIES 1934–1935

(Based Upon Estimates Made According to the Scale of Measurements)

| | (a) Service to Membership | | | | | (b) Service to Society | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | | E | F | G | H | J | K | | |
| Section | No. of meetings | Exec. comm. meetings | Assist. to Junior Mem. | Aid to Student Mem. | Total (a) | Ratio unpaid total Mem. | Ratio new Mem. to total Mem. | Cooperation with headquarters | Performance of delegate | Functioning of individual Mem. | General Sect. activity | Total (b) | Section result, points or per cent |
| Akron-Canton | 135 | 95 | 95 | 95 | 420 | 65 | 20 | 20 | 100 | 65 | 150 | 420 | 840 |
| Anthracite Leh. Valley | 150 | 100 | 25 | 50 | 325 | 32 | 17 | 20 | 120 | 50 | 130 | 369 | 694 |
| Atlanta | 150 | 100 | 20 | 100 | 370 | 20 | 22 | 20 | 100 | 55 | 150 | 367 | 737 |
| Baltimore | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Birmingham | 150 | 100 | 50 | 70 | 370 | 65 | 20 | 25 | 120 | 60 | 200 | 490 | 860 |
| Boston | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Bridgeport | 75 | 100 | 0 | 50 | 225 | 50 | 50 | 15 | 50 | 50 | 200 | 415 | 640 |
| Buffalo | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Central Pa. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Charlotte | 38 | 50 | 25 | 0 | 113 | 10 | 18 | 10 | 0 | 25 | 50 | 113 | 226 |
| Chattanooga | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Chicago | 150 | 100 | 25 | 25 | 300 | 50 | 20 | 20 | 120 | 50 | 150 | 410 | 710 |
| Cincinnati | 150 | 100 | 100 | 50 | 400 | 60 | 13 | 25 | 120 | 75 | 150 | 443 | 843 |
| Cleveland | 150 | 100 | 100 | 100 | 450 | 40 | 20 | 25 | 120 | 75 | 160 | 440 | 890 |
| Colorado | 150 | 100 | 100 | 50 | 400 | 55 | 22 | 25 | 120 | 50 | 200 | 472 | 872 |
| Columbus | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Dayton | 150 | 50 | 0 | 0 | 200 | 40 | 8 | 15 | 0 | 25 | 100 | 188 | 388 |
| Detroit | 150 | 100 | 100 | 75 | 425 | 100 | 30 | 25 | 120 | 75 | 180 | 530 | 955 |
| Erie | 75 | 100 | 50 | 0 | 225 | 50 | 40 | 25 | 120 | 25 | 100 | 360 | 585 |
| Florida | 120 | 75 | 60 | 100 | 355 | 41 | 23 | 20 | 100 | 60 | 150 | 394 | 749 |
| Green Mt. | 75 | 25 | 0 | 0 | 100 | 78 | 15 | 5 | 75 | 75 | 75 | 323 | 423 |
| Greenville | 150 | 100 | 20 | 75 | 345 | 33 | 30 | 20 | 120 | 50 | 125 | 378 | 723 |
| Hartford | 150 | 75 | 25 | 25 | 275 | 55 | 21 | 15 | 50 | 50 | 120 | 311 | 586 |
| Houston | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Indianapolis | 90 | 80 | 50 | 80 | 300 | 40 | 10 | 15 | 96 | 25 | 100 | 286 | 586 |
| Inland Empire | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Kansas City | 150 | 100 | 75 | 75 | 400 | 50 | 30 | 25 | 120 | 50 | 110 | 385 | 785 |
| Knoxville | 150 | 100 | 20 | 100 | 370 | 40 | 28 | 25 | 120 | 70 | 110 | 393 | 763 |
| Los Angeles | 150 | 100 | 75 | 50 | 375 | 100 | 10 | 25 | 120 | 75 | 180 | 510 | 5 |
| Louisville | 150 | 100 | 0 | 75 | 325 | 72 | 18 | 20 | 100 | 50 | 175 | 435 | 60 |
| Memphis | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Meriden | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Metropolitan | 150 | 100 | 100 | 80 | 410 | 39 | 18 | 23 | 120 | 80 | 180 | 460 | 870 |
| Mid-Continent | 150 | 100 | 90 | 55 | 395 | 67 | 13 | 20 | 120 | 50 | 150 | 420 | 815 |
| Milwaukee | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Minnesota | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Nebraska | 110 | 75 | 30 | 50 | 265 | 70 | 25 | 15 | 100 | 50 | 100 | 360 | 625 |
| New Britain | 150 | 100 | 0 | 0 | 250 | 75 | 20 | 25 | 120 | 60 | 175 | 475 | 725 |
| New Haven | 150 | 100 | 30 | 100 | 380 | 50 | 30 | 25 | 120 | 65 | 175 | 465 | 845 |
| New Orleans | 150 | 100 | 0 | 75 | 325 | 62 | 21 | 15 | 120 | 50 | 125 | 393 | 718 |
| North Texas | 150 | 100 | 25 | 75 | 350 | 40 | 20 | 20 | 120 | 50 | 105 | 355 | 705 |
| Norwich | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Ontario | 150 | 100 | 50 | 80 | 380 | 40 | 12 | 20 | 100 | 50 | 150 | 372 | 752 |
| Oregon | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Peninsular | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Philadelphia | 150 | 100 | 85 | 70 | 405 | 55 | 30 | 22 | 118 | 70 | 185 | 480 | 885 |
| Pittsburgh | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Plainfield | 150 | 100 | 50 | 0 | 300 | 50 | 30 | 25 | 120 | 75 | 130 | 430 | 730 |
| Providence | 150 | 100 | 75 | 75 | 400 | 75 | 15 | 25 | 120 | 75 | 200 | 510 | 910 |
| Raleigh | 150 | 75 | 50 | 50 | 325 | 80 | 11 | 25 | 120 | 25 | 80 | 341 | 666 |
| Rock River Valley | 150 | 100 | 50 | 30 | 330 | 70 | 18 | 25 | 0 | 40 | 200 | 353 | 683 |
| Rochester | 150 | 100 | 50 | 50 | 350 | 75 | 50 | 25 | 80 | 75 | 120 | 425 | 775 |
| St. Joseph Valley | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| St. Louis | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| San Francisco | 150 | 100 | 100 | 100 | 450 | 65 | 17 | 25 | 120 | 75 | 180 | 482 | 932 |
| Savannah | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Schenectady | 150 | 100 | 90 | 35 | 375 | 50 | 30 | 25 | 120 | 75 | 135 | 435 | 810 |
| Susquehanna | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Syracuse | 150 | 100 | 0 | 0 | 250 | 25 | 18 | 20 | 120 | 20 | 65 | 268 | 518 |
| Toledo | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Tri-Cities | 150 | 100 | 50 | 75 | 375 | 50 | 20 | 25 | 120 | 75 | 175 | 465 | 840 |
| Utah | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Utica | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Virginia | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Washington, D. C. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Waterbury | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Western Mass. | 150 | 100 | 0 | 0 | 250 | 20 | 22 | 25 | 60 | 50 | 100 | 277 | 527 |
| Western Wash. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| West Virginia | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Worcester | 150 | 100 | 50 | 50 | 350 | 50 | 22 | 20 | 120 | 75 | 200 | 487 | 837 |
| Youngstown | 150 | 75 | 10 | 0 | 235 | 60 | 30 | 18 | 80 | 50 | 130 | 368 | 603 |

### Regional Meetings, 1935–1936

The Committee on Local Sections has received an invitation from the Buffalo Section to hold a Regional Meeting at Niagara Falls, now scheduled tentatively for September, 1936; also an invitation from San Francisco to hold a Regional Meeting there in March or April, 1936. This will be accomplished by expanding plans for a western meeting of the Machine Shop Practice Division to include other Divisions.

### Manual for the Operation of a Section

The "Manual for the Operation of a Local Section" has been revised and distributed to officers of Local Sections.

### "Scale-of-Measurement" Revision

The method of rating and recording the activities of a Local Section as regards its service to the membership, and its service to the Society, which has been in use by the Committee since 1933, has proved extremely useful both to the Sections themselves in evaluating activities and personnel, and to the Committee in guiding and planning the work for any particular Local Section.

The "Scale-of-Measurement" has been revised and simplified. It is believed the change has improved its utility, and that it will be of more positive value.

### Junior Program

The Committee has been vitally interested in the useful participation of the Junior Member in the activities of the Local Sections, and concerned for his reception by the members of the profession and the members of the Society. An intelligent solution for the adequate reception and participation of the Junior must be found, and the Committee on Local Sections is interested in planning intelligently toward this end.

President D. B. Prentice of Rose Polytechnic Institute, a member of the Committee on Local Sections, and Chairman of the Committee on Junior Members which cooperates in this work, presented from this committee eight recommendations for stimulating and maintaining the interest and participation of the Juniors in the Society.

TABLE 2 LOCAL SECTIONS VISITED BY MEMBERS OF THE COMMITTEE ON LOCAL SECTIONS, 1934–1935

| Section | W. L. Dudley *Chairman* | R. E. W. Harrison | W. R. Woolrich | D. B. Prentice | E. Hartford *Secretary* |
|---|---|---|---|---|---|
| Atlanta | ....... | ....... | ....... | ....... | Apr. 1935 |
| Baltimore | ....... | ....... | ....... | ....... | Mar. 1935 |
| Birmingham | ....... | ....... | ....... | ....... | Apr. 1935 |
| Charlotte | ....... | ....... | ....... | ....... | Apr. 1935 |
| Chattanooga | ....... | ....... | ....... | ....... | Mar. 1935 |
| Chicago | Mar. 1935 | Mar. 1935 | ....... | ....... | Sept. 1934 |
| Cincinnati | June 1935 | ....... | June 1935 | June 1935 | Mar. & June 1935 |
| Colorado | Apr. 1935 | ....... | ....... | ....... | Oct. 1934 |
| Florida | ....... | ....... | ....... | ....... | Apr. 1935 |
| Greenville | ....... | ....... | ....... | ....... | Apr. 1935 |
| Houston | ....... | ....... | ....... | ....... | Oct. 1934 |
| Indianapolis | ....... | ....... | ....... | (Resident) | ....... |
| Inland Empire | ....... | ....... | ....... | ....... | Oct. 1934 |
| Kansas City | ....... | ....... | ....... | ....... | Oct. 1934 |
| Knoxville | Mar. 1935 | Mar. 1935 | (Resident) | Mar. 1935 | Mar. 1935 |
| Los Angeles | Apr. 1935 | ....... | ....... | ....... | Oct. 1934 |
| Metropolitan | Dec. 1934 | Dec. 1934 | Dec. 1934 | Dec. 1934 | (Resident) |
| Mid-Continent | ....... | ....... | ....... | ....... | Oct. 1934 |
| Milwaukee | ....... | ....... | ....... | ....... | Sept. 1934 |
| Minnesota | ....... | ....... | ....... | ....... | Sept. 1934 |
| Nebraska | Mar. 1935 | ....... | ....... | ....... | ....... |
| North Texas | ....... | ....... | ....... | ....... | Oct. 1934 |
| Oregon | ....... | ....... | ....... | ....... | Oct. 1934 |
| Raleigh | ....... | ....... | ....... | ....... | Apr. 1935 |
| St. Louis | ....... | ....... | ....... | ....... | Oct. 1934 |
| San Francisco | Apr. 1935 | ....... | ....... | ....... | Oct. 1934 |
| Savannah | ....... | ....... | ....... | ....... | Apr. 1935 |
| Utah | ....... | ....... | ....... | ....... | Oct. 1934 |
| Virginia | ....... | ....... | ....... | ....... | Apr. 1935 |
| Washington, D. C. | Apr. 1935 | (Resident) | ....... | ....... | Jan. 1935 |
| Western Wash. | (Resident) Apr. 1935 | ....... | ....... | ....... | Oct. 1934 |

Note: Mr. W. W. Macon attended the Annual Meeting in December, 1934, in New York City. He died on January 1, 1935.

Their accomplishment is a planning responsibility of which the Committee is keenly aware. It appreciates both the work and suggestions of the Junior Committee and promises its utmost in cooperation.

### Cooperation With Student Branches

The Committee recognizes its obligation to Student Members and Branches through staff contacts such as were made by its secretary, Ernest Hartford in his recent trip. The fine cooperation of the Local Sections whose members have arranged for attendance at Student Branch Meetings, the attendance of students at Local Sections Meetings, and the participation of students in inspection trips arranged by Sections all show the spirit of cooperation. Many Local Sections offer prizes to win the active interest of undergraduates.

### Joint Meetings of Local Sections

Sections are encouraged to hold joint meetings with the local engineering organizations and clubs, or sections of other national engineering societies. Through these joint meetings a community of interest is fostered and developed. Much of the investigation and development of the problem of engineering registration has resulted from them.

### Employment Service

The Society undertakes to assist members to secure positions, maintaining offices in New York, Chicago, and San Francisco, with the cooperation and help of other National Societies. The Local Sections have cooperated to the fullest in extending the service to engineers and employers.

### Cooperation With Other A.S.M.E. Activities

During the last few years the Standing and other Committees of the Society have felt keenly the need and perceived the necessity for cooperation to correlate their efforts and activities, that the greatest good might be obtained from their respective efforts. An effort is being made to realize this aim.

In most cases the Local Sections are the outlet for putting into effect many of the activities of the various Committees in their planned programs and activities.

The work of the Professional Divisions of the Society is invaluable to the Local Sections, as they are equipped to supply planned technical programs to be presented before Local Sections, or before meetings sponsored by Professional Divisions and held with the approval and cooperation of the Local Sections. Such meetings have been successful, but there still remains a large opportunity for the Professional Divisions to submit developed programs of a strictly technical nature which can be utilized in planning for comprehensive Sections programs.

This procedure was suggested to the Professional Divisions by the Advisory Board on Technology on January 12, 1935. Such programs when submitted will be distributed to those Sections within whose sphere of interest the subjects lie.

### Inventory and Planning

Local Sections are encouraged to devote some of their meetings to the branches of industry dominant in their locality, and to matters of public interest where the mechanical-engineering profession can make a contribution.

A most effective way in which the members of the Society can attack the problems confronting them is by adopting a program for Section activities in which those well-informed persons available to a Section may analyze the problem, thus providing suitable papers for discussion.

The Committee offers some thirty topics for which qualified speakers are available. These topics are intended to supplement programs of the Divisions and include such general topics as "American Manufacturing Technique in Competition With the World," "Engineering Functions in a War-Time Procurement Program," "The Effect of the Business Cycle on Engineering Activity," "Railroads From the Lay Engineers' Viewpoint," "Competition Between Industries," and many others of a similar trend.

The Committee has, after considerable study, outlined and put into action a planned program for the Local Sections. This planning is an effort to chart the course of the activities related to Local Sections and includes the following items:

Junior program and Section program; Section administration; Group conferences; membership development; Section policies; employment; joint relationships; field offices; cooperation with engineering faculties; representation on A.S.M.E. Council by geographical groups of Sections; services and development program for personnel; work of Engineers Council for Professional Development; cooperation with American Engineering Council; Student Branches; Meetings and Program; Professional Divisions; local engineering societies; registration of engineers; and legislation affecting engineers activities.

This program is to be fully developed in the Group, Annual, and Semi-Annual Meetings by the delegates, and put into effect by them.

The chairmen and executive committees of all Local Sections have had submitted to them a preamble of objectives for Local Section development to be supported by (*a*) The work of inventory; (*b*) Evolving a planning procedure; (*c*) The execution or realization of this plan into a working program.

The planning procedure and the hoped-for execution has been outlined above. The work of inventory is a careful summation of the possibilities inherent in the local Section that can be intelligently utilized, each possibility to be developed by a committee of the Section. This has a multiple purpose. It is to acquaint the members by Committee service of the functions of their Section, and their application to Society and public service. This in itself provides an activity of extreme importance to the members, the Section, and the Society and gives a knowledge of the work upon which the Society is engaged.

### Local Sections Papers

The Advisory Board on Technology states that worth-while papers presented at meetings of Local Sections will continue to receive

TABLE 3 MEMBERSHIP LOCAL SECTIONS, APRIL 1, 1935

| Section | Total membership Apr. 1, '35 | Oct. 1, '34 | Members in good standing | Meetings 1934–35 |
|---|---|---|---|---|
| Akron-Canton | 119 | 108 | 80 | 3 |
| Anthracite Leh. Valley | 201 | 205 | 133 | 3 |
| Atlanta | 78 | 70 | 47 | 2 |
| Baltimore | 164 | 158 | 118 | 7 |
| Birmingham | 55 | 51 | 45 | 3 |
| Boston | 551 | 501 | 394 | 5 |
| Bridgeport | 105 | 107 | 86 | 2 |
| Buffalo | 166 | 162 | 121 | 3 |
| Central Pa. | 61 | 51 | 47 | 1 |
| Charlotte | 33 | 23 | 18 | 1 |
| Chattanooga | 18 | 14 | 13 | 1 |
| Chicago | 711 | 639 | 509 | 3 |
| Cincinnati | 193 | 199 | 151 | 5 |
| Cleveland | 255 | 238 | 178 | 14 |
| Colorado | 94 | 84 | 71 | 7 |
| Columbus | 75 | 79 | 60 | 5 |
| Dayton | 63 | 73 | 45 | 3 |
| Detroit | 388 | 356 | 282 | 4 |
| Erie | 48 | 51 | 35 | 1 |
| Florida | 76 | 55 | 54 | 3 |
| Green Mountain | 37 | 37 | 28 | 1 |
| Greenville | 44 | 26 | 28 | 1 |
| Hartford | 111 | 101 | 85 | 4 |
| Houston | 113 | 112 | 74 | 2 |
| Indianapolis | 105 | 115 | 73 | 1 |
| Inland Empire | 16 | 21 | 10 | 8 |
| Kansas City | 111 | 89 | 75 | 7 |
| Knoxville | 49 | 39 | 34 | 1 |
| Los Angeles | 297 | 318 | 248 | 10 |
| Louisville | 35 | 34 | 24 | 4 |
| Memphis | 24 | 28 | 15 | 0 |
| Meriden | 25 | 25 | 14 | 1 |
| Metropolitan | 3,707 | 3,459 | 2,518 | 26* |
| Mid-Continent | 138 | 148 | 91 | 3 |
| Milwaukee | 173 | 196 | 151 | 5 |
| Minnesota | 96 | 92 | 63 | 3 |
| Nebraska | 54 | 32 | 44 | 4 |
| New Britain | 47 | 35 | 24 | 7 |
| New Haven | 86 | 88 | 54 | 3 |
| New Orleans | 93 | 83 | 75 | 6 |
| North Texas | 54 | 50 | 38 | 2 |
| Norwich | 38 | 30 | 26 | 3 |
| Ontario | 82 | 86 | 58 | 3 |
| Oregon | 53 | 52 | 27 | 1 |
| Peninsula | 42 | 50 | 30 | 1 |
| Philadelphia | 884 | 771 | 636 | 7 |
| Pittsburgh | 395 | 365 | 294 | 4 |
| Plainfield | 211 | 217 | 148 | 4 |
| Providence | 159 | 134 | 124 | 7 |
| Raleigh | 20 | 31 | 17 | 3 |
| Rock River Valley | 49 | 43 | 32 | 9 |
| Rochester | 98 | 99 | 69 | 5 |
| St. Joseph Valley | 32 | 35 | 21 | 1 |
| St. Louis | 194 | 213 | 127 | 2 |
| San Francisco | 337 | 337 | 244 | 6 |
| Savannah | 16 | 15 | 13 | 1 |
| Schenectady | 167 | 173 | 121 | 19 |
| Susquehanna | 66 | 67 | 50 | 1 |
| Syracuse | 99 | 115 | 62 | 4 |
| Toledo | 57 | 58 | 34 | 7 |
| Tri-Cities | 65 | 62 | 48 | 4 |
| Utah | 27 | 26 | 21 | 4 |
| Utica | 14 | 26 | 8 | 0 |
| Virginia | 124 | 126 | 96 | 0 |
| Washington, D. C. | 194 | 162 | 149 | 6 |
| Waterbury | 81 | 72 | 63 | 3 |
| Western Mass. | 98 | 95 | 60 | 4 |
| Western Wash. | 87 | 77 | 54 | 6 |
| West Virginia | 64 | 61 | 47 | 0 |
| Worcester | 148 | 138 | 111 | 8 |
| Youngstown | 49 | 67 | 42 | 4 |
| | 12,819 | 12,155 | 9,085 | 301 |

Membership in Society, April 1, 1935, 14,650
Membership in Sections, April 1, 1935, 12,819
Membership in Society, October 1, 1934, 14,227
Membership in Sections, October 1, 1934, 12,155

* In addition to 64 separate Junior activities.

special consideration by the Committee on Publications, and the Editor of "*Mechanical Engineering.*"

### Midwest Office

The Committee on Local Sections is glad to express the appreciation of the Sections and Student Branches in the Midwest of the fact that Council has continued the Midwest Office. Many activities and members have found the services of that office of value.

### Death of W. W. Macon

Last January Mr. Macon, whose years of effort in behalf of the Society had culminated in his service on the Committee on Local Sections, passed away suddenly and unexpectedly. Your Committee expresses its deepest regret at his loss which it and the Society feel very keenly. All will miss his analytical ability and kindly humor, both given so freely in the service of the Society.

### In Conclusion

Your Committee expresses its gratitude to the many sincere and conscientious officers and executive committees of the Local Sections in the many centers of the country for their generous cooperation, and also to the officers, staff, and Council of the Society, together with the Standing Committees for their help in, and their sympathetic understanding of, the many problems with which the membership is confronted.

Respectfully submitted,

William Lyle Dudley, *Chairman*
R. E. W. Harrison
W. R. Woolrich
D. B. Prentice

## PROFESSIONAL DIVISIONS

The Professional Divisions have had a successful year during 1934–1935. The outstanding accomplishment was the publication quarterly of the *Journal of Applied Mechanics* and the financial contributions secured by that Division from outside sources to increase the number of technical papers to be published.

During the year five national division meetings were successfully held by the following Divisions: Oil and Gas Power, May, Tulsa; Applied Mechanics, June, Ann Arbor; Graphic Arts, June, Cincinnati; Machine Shop Practice, September, Cleveland; Aeronautic, October, St. Louis. In addition the Textile Division assisted the Greenville, S. C., Section in holding a Southern textile meeting. The programs of these meetings were effectively organized with the close cooperation of the Sections and the Divisions. For the Aeronautic meeting special credit is due to the St. Louis Section for arranging preprints of the meeting papers in pamphlet form.

The Professional Divisions were particularly active during the year in organizing large technical programs for the Semi-Annual and 1935 Annual Meetings. There was a noticeable improvement in cooperative activities between the Divisions, more sessions having been jointly organized. At the 1934 Annual Meeting the Standing Committee successfully arranged the presentation of a joint progress report of the power divisions. This was presented at the close of one of the power sessions by C. F. Hirshfeld, who was assisted in the preparation of his report by the following Divisions: Fuels, Hydraulic, Oil and Gas Power, and Steam Power. It is planned to increase this type of cooperation.

An effort was made by the Divisions during the year to assist the Local Sections in securing speakers for local meetings. The Railroad Division took the lead in this line of endeavor by organizing a special committee whose members were well distributed over the country and by notifying the Sections that these members were available as speakers for local railroad meetings. The Management Division was also active in assisting in coordinating local management meetings, particularly in New York and Boston. The Machine Shop Practice Division encouraged the Sections to hold meetings on the subjects of welding and casting.

### Division Activities

*Aeronautic Division.* The Aeronautic Division held its National Meeting in October at St. Louis, Mo., under the auspices of the St. Louis Section. Over thirty-five papers were presented at the meeting and they were published by the Section in a photo-offset pamphlet, which was sold for $1.50. The Spirit of St. Louis Medal was awarded posthumously at the meeting to Will Rogers for his splendid work in advancing aeronautics.

Other activities consisted of holding a session at both the Semi-Annual and the 1935 Annual Meetings and in assisting several Local Sections in holding local aeronautic meetings. The Division has a special Subcommittee on Industrial Aerodynamics and is actively assisting both the A.S.M.E. Committee on Aircraft Safety and Inspection and the Aviation Committee of the American Engineering Council.

*Applied Mechanics Division.* The Applied Mechanics Division held its National Meeting on June 18 and 19 at the University of Michigan, Ann Arbor, Mich., under the auspices of the Detroit Section. Thirteen papers were presented at the meeting. The Division is sponsoring or participating in sessions at the 1935 Annual Meeting. It has six special subcommittees: elasticity, strength of materials, plasticity, dynamics, mechanics of liquids and gases, and thermodynamics.

This year saw the publication of the *Journal of Applied Mechanics* as a separate quarterly under the auspices of the Society. The Division secured nearly $2000 in special donations to assist in publishing more technical papers. This, however, does not as yet take care of the quantity of valuable papers that are presented, and the Division

has recommended that the *Journal* be sent only to those members requesting it so as to conserve funds for publication of additional material.

The Division is also undertaking a study of symbols and abbreviations used in applied mechanics, in cooperation with other interested groups, as a preliminary step in the preparation of a list which will be acceptable to a majority and form the basis of a recommended standard.

*Fuels Division.* The Fuels Division arranged two sessions at the Semi-Annual Meeting and two sessions at the 1935 Annual Meeting. During the year the Special Subcommittee on Fly-Ash and Cinders continued its survey to secure data that industry had accumulated. The Pure Air Committee has continued its activities. The Fuels Division is also cooperating with the A.I.M.E. in the work of the Committee on Fuel Values. This Committee has three special subcommittees on effect of ash on Btu, effect of fusion temperature of ash on fuel value, effect of sulphur with special reference to corrosive effect.

*Graphic Arts Division.* The Graphic Arts Division is the new name adopted this year for the former Printing Industries Division. The Division held its National Meeting as part of the Semi-Annual Meeting. Ten papers and lectures were presented at the National Meeting, which was held jointly with the Graphic Arts Research Bureau. The Bureau was organized at the Division's National Meeting in Philadelphia in October, 1934. The object of the Bureau is to coordinate, stimulate, and sponsor research in the Graphic Arts field. The Bureau at its Cincinnati meeting voted to request affiliation with the Society. Membership in the Bureau consists of about 400 individual members and three affiliated organizations. The Bureau and the Division are planning a National Meeting to be held in Washington, D. C., in March or April, 1936.

*Hydraulic Division.* The Hydraulic Division held a session on Hydraulic Turbine developments at the Semi-Annual Meeting in Cincinnati. At the 1935 annual meeting, two sessions will be devoted to the study of Cavitation and have been arranged in cooperation with the Power Division of the A.S.C.E. and the Applied Mechanics Division of the A.S.M.E.

The Division is continuing the activities of the Water Hammer Committee and has secured the cooperation of many prominent engineers in other societies and in various foreign countries. Plans are being completed for a second symposium on Water Hammer in December, 1936.

*Iron and Steel Division.* The Iron and Steel Division held one session at the Semi-Annual Meeting and two sessions at the 1935 Annual Meeting, one of which was held jointly with the Applied Mechanics Division.

*Machine Shop Practice Division.* The Machine Shop Practice Division held four sessions and cooperated with the Railroad Division in a fifth at the Semi-Annual Meeting. For the 1935 Annual Meeting two sessions are planned and a joint luncheon with the Job Shop Committee of the Management Division. The Division also cooperated in the Machine-Tool Congress held in Cleveland, Ohio, and jointly with the Cleveland Section, held two evening meetings on September 10 and 11. At the beginning of the year the Lubrication Engineering Subcommittee of the Petroleum Division was transferred to the Machine Shop Practice Division and reorganized. Other subcommittees are: foundry, welding, and machine design. The Division also has liaison connection with the Research Committee on Cutting Metals, Cutting Oils, and Gears. The Foundry Committee together with the Birmingham Local Section and the American Foundrymen's Association held a two-day meeting on February 28, and March 1, 1935. Several Local Sections held meetings on the subjects of welding and casting as a result of the Division's suggestions and cooperation. These meetings were well attended and created considerable interest.

*Management Division.* The Management Division sponsored three sessions at the Semi-Annual Meeting and is sponsoring four sessions at the Annual Meeting as well as cooperating in a luncheon and one other session. The Division has started work on a Supplement to the Bibliography of Management Literature to cover literature published from January, 1931, to date.

The Management Division assisted the National Management Council in securing papers for the Sixth International Congress for Scientific Management held in London, England, during July, 1935, and on behalf of the National Management Council planned and organized a series of nine joint meetings to be held in the New York Metropolitan area during 1935–1936 in which local sections of ten societies and associations interested in managerial affairs will participate.

During the past year the Waste Elimination Committee has been active in sponsoring sessions at the Semi-Annual and Annual Meeting.

The Job Shop Management Committee is to hold a joint meeting with the Machine Shop Practice Division at the coming Annual Meeting and it has developed considerable interest in Job Shop Management problems by sending out several questionnaires during the year.

The Marketing Committee has undertaken a national survey to determine the present status of marketing research in industry and has also in the course of preparation a Bibliography of Literature on Marketing Research.

The Division has the following subcommittees: Economics, human relations, job shop management, management research, marketing, quality control, time and motion study, waste elimination, and statistics in industry. It has representation in the National Management Council.

*Materials Handling Division.* The Materials Handling Division was active this year for the first time in several years and sponsored three sessions at the Semi-Annual Meeting in Cincinnati.

*Oil and Gas Power Division.* The Oil and Gas Power Division held its Eighth National Meeting on May 8 to 11, 1935, in Tulsa, Okla., in cooperation with the Mid-Continent Section. There were presented nine technical papers which were preprinted in the *Oil and Gas Journal* and *Diesel Power.* The division will have a session at the 1935 Annual Meeting.

The special Subcommittee on Oil-Engine Cost will present its seventh yearly report at the 1935 Annual Meeting. This report for the year 1934 covers over one hundred and fifty plants. The report is available in pamphlet form and may be purchased from the Society.

*Petroleum Division.* The Petroleum Division is holding a session at the 1935 Annual Meeting. The subcommittees were active in the Mid-Continent area and a series of local meetings was held in Tulsa. The Subcommittee on Lubrication Engineering was transferred this year from the Petroleum Division to the Machine Shop Practice Division. The Division is planning a national meeting next year to be held at the time of the Petroleum Exposition in Tulsa, Okla., in May, 1936.

*Power Division.* The Power Division held two sessions at the Semi-Annual Meeting and has planned three sessions at the 1935 Annual Meeting besides a cooperative session with the Applied Mechanics Division. The Industrial power group has planned to hold, at the 1935 Annual Meeting, its usual Wednesday luncheon conference. Among the special research committees in the power field the Boiler Feedwater and Steam Research committees are planning to hold sessions at the 1935 Annual Meeting.

*Process Division.* The Process Industries Division continued its active role during its second year. At the Annual Meeting the Subcommittee on Sugar will hold a session, its Subcommittee on Heat Transfer will hold two sessions on radiant heat and cooperate in a third session. The Subcommittee on Drying presented at the Semi-Annual Meeting its recommended practice on Testing Drying Equipment and is sponsoring a session on Dust Separation at the 1935 Annual Meeting. The Air Conditioning Subcommittee held a Metropolitan Section meeting in October. The Heat Transfer Committee has issued in pamphlet form the previous papers presented at its sessions. The Division has developed relations with the American Institute of Chemical Engineers and the American Ceramic Society both of which have appointed liaison representatives.

*Railroad Division.* The Railroad Division held a joint session with the Machine Shop Practice Division at the Cincinnati Semi-Annual Meeting and has planned to hold at the 1935 Annual Meeting two sessions, including a symposium on Railroad Lubrication. Besides this the Division will hold a joint session with the Applied Mechanics Division. During the year the Division organized in order to assist certain Local Sections that might appropriately hold local railroad meetings.

*Textile Division.* The Textile Division plans to hold its session at the 1935 Annual Meeting in cooperation with the Graphic Arts and the Management Divisions. There will also be the usual luncheon conference after the Annual Meeting session. The Division assisted the Greenville Section of the Society in holding a meeting there on April 10 during the Southern Textile Exposition. This meeting was to have been held in October, 1934, but was postponed until the spring of 1935.

*Wood Industries Division.* The Wood Industries Division held a two-session symposium on Wood Housing at the Cincinnati Semi-Annual Meeting. The Division is holding a session at the 1935 Annual Meeting on Modern Timber Construction.

Respectfully submitted,

W. A. Shoudy, *Chairman*
K. H. Condit
G. B. Pegram
Crosby Field
L. K. Sillcox

## MEMBERSHIP

The Committee on Membership submits the following statistical report covering the recommendations of the Committee to Council during the fiscal year October 1, 1934, to October 1, 1935:

### Report

The Committee on Membership held twelve regular monthly meetings during the fiscal year 1934–1935.

The following are the applications considered in the transaction of its work and a summary showing the action taken:

| | |
|---|---|
| Applications pending October 1, 1934 | 137 |
| Special cases before Council | 57 |
| Applications received during fiscal year 1934–1935 | 2206 |
| Total applications handled during the year 1934–1935 | 2400 |
| Recommended for membership | 2222 |
| Transfers denied | 3 |
| Deferred | 4 |
| Withdrawn, incomplete, and canceled | 40 |
| Applications pending October 1, 1935 | 131 |
| Total applications handled during year 1934–1935 | 2400 |

The 2222 recommended for membership were divided into the following grades:

| | |
|---|---|
| Members | 104 |
| Transfers to Member | 89 |
| Transfers from Student Member to Member | 1 |
| Associates | 3 |
| Associate-Members | 79 |
| Transfers to Associate-Member | 107 |
| Transfers from Student Member to Associate-Member | 2 |
| Juniors | 165 |
| Transfers from Student Associate to Junior | 76 |
| Transfers from Student Member to Junior | 1596 |
| Total recommended | 2222 |
| Transfers | 196 |
| Total new members recommended | 2026 |

During the fiscal year 1934–1935 the Committee on Membership made the following recommendations:

| | |
|---|---|
| Transfers from Student Member to Junior declared void | 735 |
| Elections to other grades declared void | 28 |
| Total elections declared void | 763 |

During the year closing, the Committee has devoted a portion of several meetings in addition to special meetings to joint discussion with the Secretary and also representatives of other Committees interested in effecting the proposed changes in the Constitution and By-Laws[1] pertaining to Membership, as the Amendments now appear on page 532 of the August, 1935, issue of *Mechanical Engineering*.

Certain changes in the By-Laws have been suggested by the Membership Committee, including the recommendation that the title of the Standing Committee on Membership be changed to the Standing Committee on Admissions.

A canvass of all Local Sections was initiated through a letter of April 5, 1935, from the chairman of the Committee on Membership to the chairmen of the Local Sections, requesting a report from the Executive Committees stating whether or not they wish, in the future, to receive a copy of the professional record of every applicant for membership within their respective territories.

The following response resulted: Thirteen replies were received in which four wish full copy of record, and nine wish only special cases referred to them.

A new reference form for new members and transfers has been adopted.

The committee now has under consideration the policies which will govern the effective administration of its work of passing on applications not only for the proposed grade of Fellow but for all other grades in order to maintain the highest standard obtainable.

Respectfully submitted,

H. A. Lardner, *Chairman*
R. H. McLain
C. L. Davidson
L. R. Ford
F. C. Spencer
O. E. Goldschmidt, *Advisory Member*

## CONSTITUTION AND BY-LAWS

For some little time it has been appreciated that there should be somewhat more uniformity in the admission requirements for the several grades in the national engineering societies and recommendations have been made from time to time that our Society and others should add the grade of Fellow to give recognition to the senior engineers who have achieved distinction in the engineering field.

To meet these needs the Committees on Policies and Budget, and Membership, at the request of Council, submitted to the Committee on Constitution and By-Laws a draft of suggested amendments along these lines, which amendments as revised were submitted to the membership in the usual printed ballot form in August, 1935, for vote to be announced at the Annual Meeting in December.

The new articles of the Constitution divide the membership into two groups, the first, including all of the voting members, is to be entitled the "Corporate Membership" which consists of the new grade of Fellows, the Members, and the Junior Members. The second group will also include three grades, namely, Honorary Members, Associates, and Student Members.

The requirements for Fellow are such as to insure that the grade shall have the proper distinction. It is not necessary that one should be able to meet the full requirements if exceptionally qualified because provision has been added that the Council may, by unanimous vote, elect a Fellow who has distinguished scientific attainments. In order to form the nucleus of Fellow a temporary provision permits any past or present member of Council to apply for the grade of Fellow and if properly qualified to become a Fellow automatically. This section was a controversial one but in the form submitted to the membership is thought to be in accord with the wishes of the membership at large. The Associate Members have been advanced to the grade of Member if over thirty years of age and will be automatically advanced upon reaching that age so that in a few years the present grade of Associate Member will be abolished.

The new amendments to the By-Laws which have been reviewed and proposed for approval by the Council include a change in the title and duties of the Standing Committee on Membership and in a rewording of Paragraph 3 of Article B14 providing that the income from initiation fees shall not be used for current expenses but shall be added to the surplus at the close of each fiscal year. This change makes no real alteration in the method of handling funds but does simplify the bookkeeping and will aid the auditors in their annual report.

Respectfully submitted,

H. H. Snelling, *Chairman*
Richard Kutzleb, Jr.
Herbert B. Lewis
Wm. H. Kavanaugh
R. D. Brizzolara
G. N. Cole, *Junior Adviser*

## RELATIONS WITH COLLEGES

The past year was notable in the history of the Committee because of the fact that it saw the completion of the new plan and of changing from the old system of operating Student Branches to the new. This was accomplished through the introduction of the plan in the early part of the college year when a visit was made by a representative of the Committee to each of the colleges which comprise Groups VI and VII.

Naturally the number of members in Student Branches enrolled under the new plan increased considerably and reached a total membership of 3250. This further development of the plan was sufficient to encourage the presentation at the Semi-Annual Meeting, Cincinnati, of an amendment to the Constitution of the Society providing for the grade of Student Member, and also to suspend the initiation fee of these Student Members who transfer to the grade of Junior within a limited time after graduation. In the 112 colleges a total of 336 meetings were held.

The economic conditions of the country, while improved, have not created a sufficient demand for recent graduate engineers to show any marked increase in the number of Student Members transferred to the grade of Junior upon graduation. Of 1318 Student Members graduated with the class of 1934, 530 completed their transfer to Junior membership by the payment of the initiation fee. The loss of the remaining 800 can be accounted for largely because of the eco-

TABLE 1 COMPARISON OF BRANCH ACTIVITIES BY GROUPS

| Group | No. of branches | Avg no. meetings per branch | Avg attendance per meeting |
|---|---|---|---|
| I | 15 | 7 | 42 |
| II | 18 | 4 | 41 |
| III | 51 | 8 | 37 |
| IV | 16 | 5 | 39 |
| V | 17 | 6 | 54 |
| VI | 15 | 6 | 36 |
| VII | 15 | 5 | 24 |
| Puerto Rico | 1 | – | — |

[1] See Report of the Committee on Constitution and By-Laws, page 8.

TABLE 2 GROUP MEETINGS, 1935

| Prize | Recipient | Title of Paper | College |
|---|---|---|---|
| | | **Group I, New England Student Meeting, Cambridge, Mass.** Attendance: 175 Papers presented: 11 | |
| First | H. T. Sawyer | Development and Investigation of an Indicator for High-Speed Engines | Rensselaer Poly. Inst. |
| Second | R. F. Hopkins | Effect of Transverse Slots and Holes on the Torsional Properties of Shafting | Brown University |
| Third | H. B. Kimball | Problems in Miniature Design | Mass. Inst. of Tech. |
| Fourth | W. R. Steur | Water Channel Method of Flow Visualization | Worcester Poly. Inst. |
| | | **Group II, Eastern Student Meeting, New York, N. Y.** Attendance: 225 Papers presented: 10 | |
| First | Benjamin O. Delaney | Engine Indicators | Princeton Univ. |
| Second | John A. Sauer | A New Apparatus for Testing Materials in Combined Bending and Torsion | Rutgers Univ. |
| Third | Alan S. Compton | Maintenance Welding | Drexel Inst. |
| Fourth | John R. Blizard | Air Resistance of Tube Bundles | Poly. Inst. of Brooklyn |
| | | **Group III, Alleghenies Student Meeting, State College, Pa.** Attendance: 175 Papers presented: 10 | |
| First | Philip S. Criblet | The Precipitation of Dust From Flue Gases | Johns Hopkins Univ. |
| Second | R. L. Homsher | Governing Hydraulic Turbines for Best Efficiency | Penn State College |
| Third | Wm. Leavenworth | The What and Why of a Whirling Arm | Univ. of Akron |
| Fourth | J. J. Prendergast | Tests on a Streamlined Power Craft | Case School of Applied Science |
| | | **Group IV, Southern Student Meeting, Knoxville, Tenn.** Attendance: 180 Papers presented: 13 | |
| First | A. C. Todd | Economic Aspects of Stream Lining for Automobiles | Georgia School of Tech. |
| Second | H. B. Edwards | Uses of Glass in Mechanical Engineering | Univ. of Virginia |
| Third | Luke R. Hadnot | A Dryer for the Artificial Dehydration of Forage Crops | Louisiana State University |
| Fourth | John R. Kilgore | A New Kind of Mirror | Vanderbilt Univ. |
| | | **Group V, Midwest Student Meeting, Chicago, Ill.** Attendance: 210 Papers presented: 15 | |
| First | Edw. J. Wellauer | A Mathematical Determination of the Contact Length of Helical and Herring-bone Gearing | Marquette University |
| Second | Einar W. Jensen | Stresses in an Automobile Engine Crankshaft | Univ. of Iowa |
| Third | Janus DeHamer | The Development of a Test for Set in Split-Bamboo Fishing Rods | Mich. College of Mining & Tech. |
| Fourth | Walter Schlagel | Employment Conditions Among Recent Engineering Graduates | Iowa State College |
| | | **Group VI, Northern Unit Student Meeting, Lincoln, Neb.** Attendance: 75 Papers presented: 9 | |
| First | E. D. Beachler | Diesel Boilers | University of Nebraska |
| Second | Harold Grasse | Artistic Industrial Design | Univ. of Kansas |
| Third | H. C. Bates | A Study of Causes of Failures of Tubes in Refinery Cracking Stills | Kansas State Agri. College |
| Fourth | H. E. Simonson | The Regenerative Vapor Cycle | Univ. of Nebraska |
| | | **Group VI, Southern Unit Student Meeting, Dallas, Texas** Attendance: 116 Papers presented: 13 | |
| First | Glenn W. King | Combining Motion Study and Machine Design for Efficient Production | Rice Institute |
| Second | Saviour Perrone | Steam Jet Vacuum Refrigeration | Univ. of Texas |
| Third | Alex W. Francis | Some Aspects of Increasing Ultimate Recovery of Crude Oil From Natural Reservoirs | Univ. of Oklahoma |
| Fourth | W. C. Rodgers | Application of Refrigerating Cycle to the Heating and Cooling of Buildings | Texas A. & M. College |
| | | **Group VII, Northwest Student Meeting, Seattle, Wash.** Attendance: 110 Papers presented: 10 | |
| First | Robt. E. Laughlin | The Diesel Field | Univ. of Washington |
| Second | James Kratzer | The Photoelectric Cell | Wash. State College |
| Third | Robert D. Watt | Design of a Universal Air Conditioner | Univ. of Washington |
| Fourth | Edward Wegman | Air Conditioning at High Altitudes | Montana State College |
| | | **Group VII, Central Unit Student Meeting, Boulder, Colorado** Attendance: 95 Papers presented: 7 | |
| First | Carl L. Ritter | Cooling of Boulder Dam | Colorado State College |
| Second | Thomas R. Mackay | San Gabriel River Flood Control | University of Utah |
| Third | Alvin Welton | Brake Equipment on Modern High-Speed Trains | Colorado State College |
| Fourth | Harry L. Hoffman | Discussion of Flotation | Univ. of Colorado |
| | | **Group VII, Southwestern Student Meeting, Berkeley, Calif.** Attendance: 106 Papers presented: 17 | |
| First | Bradley H. Young | Design of Oleo-Pneumatic Shock Absorbers for Aircraft | California Inst. of Technology |
| Second | Byron Masterson | Spot Welding in Thin Sheet Structures | University of California |
| Third | A. L. Buonaccorsi | Seismogram Wave Analysis | Santa Clara Univ. |
| Fourth | Clyde C. Chivens | The Pump-Testing Laboratory of the Metropolitan Water District of Southern California | California Inst. of Tech. |

nomic conditions which made it impossible for them to obtain engineering employment or perhaps any employment.

Another important development during the past year was the extension of Student Meetings from five in number to ten, made necessary by the addition of Groups VI and VII. The geographical area covered by these Groups is so enormous that it is impractical to schedule a single meeting for each Group with the expectation of any reasonable attendance from all of the colleges within the Group area. Therefore, the Committee deemed it wise to arrange two meetings for Group VI and three meetings for Group VII. The other Groups comprise practically all colleges east of the Mississippi and have but one meeting for all colleges in each Group.

Only twice in the history of the Student Branches has any Branch been discontinued. Last year the University of South Dakota discontinued its course in mechanical engineering, and this year upon request of the Student Branch at Harvard University it was discontinued. One new Student Branch was authorized at the Northwestern University, Evanston, Illinois.

The Committee is pleased to report that it was able to authorize five loans to Student Members from the Max Toltz Fund amounting to $850, thus enabling these students to continue their engineering studies.

Eugene W. O'Brien resigned from the Committee but was persuaded to serve as advisory member. Edward W. Burbank was appointed to fill his unexpired term.

Respectfully submitted,

William L. Abbott, *Chairman*
Edward W. Burbank
Roy V. Wright
William A. Hanley
F. V. Larkin
Eugene W. O'Brien, *Advisory Member*

## AWARDS

The Committee on Awards made the following recommendations to the Council for awards which were to be presented during the fiscal year 1934–1935:

*A.S.M.E. Medal* to Willis H. Carrier, for his pioneer work in air conditioning.

*Holley Medal* to Irving Langmuir, for his contributions to science and engineering, including the development of gas-filled incandescent lamps, thoriated filament for thermionic emission, atomic hydrogen welding, phase-control operation of the thyratron tube, and fundamental research in oil films.

*Worcester Reed Warner Medal* to Ralph E. Flanders, for his contributions to a better understanding of the relationship of the engineer to

economic problems and social trends as exemplified by the many papers which he has presented.

*Junior Award* to John I. Yellott, Jr., for his paper, "Supersaturated Steam."

*Charles T. Main Award* to Philip P. Self, for his paper on "Air Conditioning—Its Practicability and Relation to Public Welfare."

*Student Award, Undergraduate,* to H. Reynolds Hudson, for his paper on "Dynamic Balance and Functional Utility Applied to Automatic Design."

No recommendations were made for the Melville Medal and Postgraduate Student Award.

The topic for the 1936 Charles T. Main Award is "Development in the Generation and Distribution of Power and Their Effect Upon the Consumer."

Upon recommendation of the Committee on Policies and Budget, the Council approved the extension of the work as heretofore carried on whereby a Board of Honors would be established. Council named the same personnel on the Board of Honors as comprises the Committee on Awards. It was understood that the Board of Honors would operate in an advisory or trial capacity for a period of two years. Acting in this capacity they proceeded to study and make recommendations regarding changes in the By-Laws and Rules of the Society and methods of procedure.

The first recommendations made to Council were as follows:

*Resolved* that the By-Laws be duly amended to change Par. 23 of Article B-8 of the By-Laws which now reads: "The Standing Committee on Awards shall, under the direction of the Council, have supervision of the awards of the Society as detailed in the Rules or prescribed by Council. The Committee shall consist of five (5) members and the term of one member shall expire at the close of each Annual Meeting," to the following:

"The Board of Honors and Awards shall, under the direction of the Council, have supervision of the awards of the Society as detailed in the Rules or prescribed by Council. Recommendations for representatives on joint bodies of award shall be made to Council by this Board. The Board shall consist of five (5) members, and the term of one member shall expire at the close of each Annual Meeting". . . .

*Further resolved* that the Board of Honors and Awards shall be authorized to constitute a Medal Committee to be comprised of twenty (20) persons, five of whom shall be the members of the Board of Honors and Awards, and in addition fifteen persons, three appointed each year for a period of five years.

It is anticipated that this Medal Committee will suitably organize itself into a functioning body which shall be charged with the duty of recommending to the Council nominations for the A.S.M.E. Medal, the Holley Medal, the Warner Medal, and in addition thereto nominations for representatives of the Society on joint Boards of Award.

The Board desires to provide better methods for the review of papers submitted for awards and intends to experiment with various means to this end. For this year the Publications Committee has been asked to submit its recommendations regarding papers that should be considered for the Melville Medal and the Junior Award. These papers will be reviewed by qualified persons or agencies and through them a recommendation made to the Board. It is expected that student papers may be reviewed by the faculties of the various universities under a plan to be definitely formulated and the assistance of the Committee on Relations With Colleges will be invited to this end.

The objective behind these recommendations is, first, that there should be a single responsibility for all awards in which the Society is interested; second, that there should be a body of highly representative members of the Society who may give to the consideration of awards, the attention which the subject deserves; and third, that the creation of the Medal Committee would afford a body which should be particularly charged with forward-looking plans and policies, not alone for those honors which are now available but for others which may later be available for various types of recognition.

It is the belief of the present Standing Committee on Awards that these suggested steps will contribute to the elevation of the whole awards situation and will enable them to be used in a larger manner to the good of the Society and the profession.

The nominations which the Awards Committee offered to the Council for the Medal Committee cover the fields of education, technical journalism, consultation, and industry, and represent a geographical cross section of the membership as well. The names are: E. O. Eastwood, A. M. Greene, Jr., D. C. Jackson, R. H. Fernald, J. H. Herron, F. M. Gunby, J. L. Harrington, H. C. Meyer, Jr., K. H. Condit, R. V. Wright, Robert Sibley, J. W. Parker, C. L. Bausch, E. R. Fish, and L. W. Wallace.

Respectfully submitted, W. L. Batt, *Chairman*

R. C. H. Heck — Herman Diederichs
Harte Cooke — L. P. Alford

## EDUCATION AND TRAINING FOR THE INDUSTRIES

Due to several changes in the personnel the Committee on Education and Training for the Industries was reorganized during the year.

One of its important activities was the evolving of a statement of its objectives as it is felt that the opportunities for this Committee have broadened and become considerably more important because of the changed economic conditions during the past five years.

The Committee sponsored a session at the Annual Meeting of the Society and at its Semi-Annual Meeting. The session was well attended and caused much favorable comment.

Respectfully submitted,

George A. Seyler, *Chairman*
Clement J. Freund — John A. Randall
John Younger — Warner Seely

## LIBRARY

The work of the Engineering Societies Library has been carried on steadily during the year with marked appreciation by its users. These numbered over forty thousand, of whom over ten thousand were members living at a distance who were assisted by correspondence.

Sixty-five hundred books were added in 1934 to the collection, which now contains about 147,000 volumes and maps.

The conditions portrayed so graphically in our report of last year still continue to hamper the growth of this useful activity.

The Library is called upon for a constantly increasing variety of services. More and more it is becoming a general information bureau for the profession, as well as its outstanding depot for the literature. An increasing demand for assistance constantly calls for more books, increased staff, and larger quarters. With a budget much lower than it was five years ago, it is impossible to provide these facilities. We trust that the time is near when more generous provision may be made for this important activity, which at some time or another is used by almost every member of the Society.

Respectfully submitted,

E. P. Worden, *Chairman*
G. F. Felker — J. S. Kerins
L. K. Sillcox — C. E. Davies, *Ex-Officio*

## RESEARCH

A review of the annual reports of the Society's special research committees reveals an unexpected amount of activity and strength in organization. Only five of the twenty-four committees reported no activity during the year and a considerable number of them have functioned in a normal way.

As in previous years, a number of these committees have sponsored sessions at the general meetings of the Society or have provided the papers for the programs of other meetings set by the A.S.M.E. and similar organizations. For example, during the 1934 Annual Meeting the following five special research committees sponsored and conducted regular technical sessions; Fluid Meters, Thermal Properties of Steam, Cutting of Metals, Mechanical Springs, and Boiler-Feedwater Studies. In addition, three committees, Fluid Meters, Wire Rope, and Cottonseed Processing, cooperated with certain A.S.M.E. professional divisions in the preparation of the programs for three other sessions.

At the Society's Semi-Annual Meeting in Cincinnati in June and the Machine-Tool Congress in Cleveland in September the committees on the Cutting of Metals and Mechanical Springs supplied papers for certain of the technical sessions sponsored by the professional divisions.

The financial condition of the committees has remained much the same this year as it was last. Approximately $3000 was secured from industry. The Engineering Foundation has been both considerate and generous in its responses to the requests for assistance addressed to it by several of the committees. In all $7500 was given as grants and an added $1500 was pledged as a loan to the Subcommittee on Metal-Cutting Data. This latter sum is intended to assure prompt publication of the first of the series of handbooks to be issued by this committee.

Sometimes the members of administrative committees such as the Research Committee are tempted to be skeptical as to the value of the results accomplished by an activity for which they are responsible. At such times it is reassuring to find, in the reports of a special committee, statements such as the following which was taken from the report of the Committee on Lubrication:

"An interesting letter was received a few days ago from Mr. F. P. D. of the M. C. Company. After describing the work of his company in installing oil-film roll-neck bearings to withstand shock loads exceeding 1,500,000 pounds, he says: 'The operating $ZN/P$ for these bearings is low. But, according to experiments made by the members of the lubrication committee, with this factor as a criterion, these bearings should and do perform satisfactorily. I know of no better way to pay tribute to the efforts of the committee than to outline this example of a very practical use of the reports of the Special Research Committee on Lubrication.' "

Brief reports of the special and joint research committees which were organized and are sponsored by the Society will be found in the following sections of this report.

### Special and Joint Committee Reports

*Lubrication*, A. E. Flowers, Chairman. A successful meeting of the A.S.M.E. Special Research Committee on Lubrication was held in New York on December 5, 1934. Reports were received on the Committee's activities from the members present. The chairman made a statement concerning the committee's funds which covered an expenditure of approximately \$500 and a balance on hand of \$524. Mr. Hersey reported on the progress he had made in the preparation of abstracts of the 249 papers listed in the committee's selected bibliography. Approximately 100 have been completed. He presented specimens of these abstracts and after discussion it was decided to reduce further the number of titles in the selected bibliography to those papers of prime scientific importance and to include in each of the abstracts the usable data and the summary or conclusions given in the paper. A general discussion of the work of the committee followed during which the members reported a total of 12 papers prepared during the year or in course of preparation by members of the committee or their immediate associates.

A reorganization of this committee is under way in order that a broad program of work may be undertaken that will cover both the physics and chemistry of lubrication and practical service problems. To this end the Society's Research Committee at its meeting in December, 1934, appointed a special Survey Committee on Lubrication to investigate the possibilities and to formulate a program.

This committee under the chairmanship of N. E. Funk held two meetings in March and May, 1935, and subsequently presented its report to the Research Committee. It was unanimous in its recommendation that the A.S.M.E. should continue to sponsor a special Research Committee on Lubrication. A consideration of the scope of the project in the light of a review of the 19 years of activity of this special research committee led to the recommendation that the scope of the reorganized committee should be broad enough to give it freedom in the selection of problems but narrow enough to insure the interest of industry. The proposed scope is to include the following: (1) Investigations of the fundamental physical and mechanical problems of lubrication, (2) interpretation of the results of research in this field for practical application, and (3) coordination of data from contemporary research in lubrication.

*Fluid Meters*, R. J. S. Pigott, Chairman. The Special Research Committee on Fluid Meters has had as its principal work for the year the completion of the revision of Part 1, "Fluid Meters—Their Theory and Application." This revision is divided into three sections: Section $A$ on the classification and nomenclature of fluid meters, Section $B$ on the theory of fluid measurement, and Section $C$ which is to contain figures and tables for use in solving practical fluid-measurement problems and illustrative examples. The Committee expects that the completed revision will be ready for publication early in 1936.

The joint research on orifice coefficients for the measurement of air and water was completed by the A.G.A.-A.S.M.E. Joint Committee on Orifice Coefficients in the fall of 1934 and the final report on these studies is now practically completed.

At present the special committee is perfecting its plans for research at the National Bureau of Standards on flow nozzles. This program is being developed in cooperation with the A.S.M.E. Power Test Codes Committee and a campaign to raise the necessary funds is under way. H. S. Bean will be in direct charge.

Though no reports have been received this year from Prof. W. H. Carson the committee understands that he is continuing his experimental work on meter coefficients for use in measuring viscous fluids at the University of Oklahoma.

*Thermal Properties of Steam*, W. L. Abbott, Vice-Chairman. Following the Third International Steam Tables Conference held in the United States in September, 1934, there has been a natural pause in the work assigned to the special research committee. Prof. J. H. Keenan undertook for the committee the preparation of the summary of the results of the conference. A revised skeleton table is its principal part. This report will be published in the November, 1935, issue of *Mechanical Engineering*. With the completion of the committee's present program Alex Dow asked to be relieved of his duties as chairman. His resignation was accepted with much regret but he was urged to continue to serve as a member of the committee.

*Strength of Gear Teeth*, R. E. Flanders, Chairman. The financial assistance given by the Engineering Foundation has made it possible for the Special Research Committee on the Strength of Gear Teeth to keep a research assistant engaged since the beginning of 1935 on tests of the surface fatigue of materials in rolling contact under the direction of Prof. Earle Buckingham. Tests have been made on rolls one inch wide with diameters up to four inches. In all of these tests, one roll was of hardened and ground steel. The mating rolls were of several varieties of cast iron, leaded brass, chilled phosphor bronze, and phenolic laminated material. A progress report on these tests is now in preparation.

With these materials, the tests indicate a tendency of an outer lamina of the material to travel by plastic flow in the direction of rolling, and also for this lamina to start to shear under the surface. On some of the cast-iron alloys, it is not yet certain whether the initial failure starts below the surface, or starts at the surface. It is hoped that investigations may be continued with other combinations of materials, and that it will be possible also to make still further tests with the same combinations of materials under combined rolling and sliding contact. Thus far, the tests have shown a very consistent relationship between load and number of repetitions of stress to cause surface failure, giving hopes that some definite relationships may eventually be established between surface fatigue and flexural or bending fatigue. Such tests take much time, but the information to be obtained from them will be invaluable to the designer in the selection of combinations of materials to avoid or minimize wear.

*Cutting of Metals*, Coleman Sellers, 3rd, Chairman. The work of this Committee during the past year consisted mainly of coordinating and encouraging the work of its four subcommittees. The personnel of the special committee has been enlarged and changed to include only those taking an active part in the work.

*Metal Cutting Data*. The Subcommittee on Metal Cutting Data formed to carry on the work so ably started by Frederick W. Taylor has been engaged for the past three years in examining all available experimental data on the cutting of metals, supplementing this with research of its own, and preparing the data thus obtained for publication in the form of handbooks for the use of industry. This should be a very valuable contribution to metal manufacturers as there is nothing of its kind in existence although the need for it has long been felt. The subcommittee has been generously supported by the Engineering Foundation. In June, 1935, the Foundation agreed in addition to underwrite the preparation of the first publication to the extent of \$1500. During the coming year, the subcommittee expects to bring this first handbook on the Cutting of Metals with Single-Pointed Paring Tools to publication. It is also continuing to encourage experimental work already under way in various parts of the country in an effort to bring them to successful conclusions. L. P. Alford is chairman of this special research committee and R. C. Deale is its secretary.

*Cutting Fluids*. During the past year the Subcommittee on Cutting Fluids has been reorganized and enlarged under the chairmanship of Prof. O. W. Boston, of the University of Michigan. The sixth progress report of the committee was presented at the semi-annual meeting of the Society in Cincinnati in June in the form of a paper entitled "The Influence of Cutting Fluids on Tool Life in Turning Steel," by Messrs. Boston, Gilbert, and Kraus. The committee has prepared a research program of a comprehensive nature and is now attempting to raise funds from industry which, with the \$1000 grant from the Engineering Foundation already appropriated, will be used in a research on cutting fluids with particular reference to the influence of cutting fluids on the tool life of single-point tools. Various physical and thermal properties of the oils also will be determined, and it is hoped that a correlation between all known properties may be obtained by which specifications may be set forth for use in selecting the proper cutting fluid to give tool life, low power, or good finish as desired on any particular material.

*Bibliography*. The Subcommittee on Bibliography on the Cutting of Metals issued its second report during the past year. This new portion of the bibliography is a continuation of Part I, published in 1930, and consists of 1257 new references with abstracts.

*Metal Cutting Materials*. The accomplishment of the Subcommittee on Metal Cutting Materials during the year will be its report on the "Questionnaire on the use of New Cutting Materials." This questionnaire was sent out to approximately 750 concerns in April, 1935. A detailed report on the data and information received was made at the Machine-Tool Congress held in Cleveland, Ohio, in September, 1935, during one of the sessions sponsored by the A.S.M.E. Machine Shop Practice Division. In addition this subcommittee has

discussed the important development of the diamond-impregnated wheels for the shaping of the cemented carbides, and expects to sponsor a paper regarding the same in the near future.

The special Research Committee on the Cutting of Metals has felt severely the lack of funds for publication by the Society. This has made it increasingly difficult to obtain research papers. Some means should be found to preserve for reference, papers of this type which, although not of wide and popular interest, are nevertheless valuable as contributions to the extremely large subject of the cutting of metals.

*Mechanical Springs*, J. R. Townsend, Chairman. The Special Research Committee on Mechanical Springs held one meeting during the past year in December, 1934. Two research programs have been practically completed during this period. The research at Wright Field directed by J. B. Johnson, chief of the Materials Branch of the Air Corps, has progressed to the point where the report is in preparation. This work covers fatigue tests on large-size helical springs. The second study by E. E. Weibel on the correlation of spring-wire torsion and fatigue data for small wire springs under the sponsorship of Prof. F. P. Zimmerli and his subcommittee at the University of Michigan has been completed and the report presented. This work was supported by funds subscribed by industry. Dr. D. J. McAdam's work on a monograph entitled "A Résumé of the Physical Properties of Spring Materials" has been carried forward and a portion of this report was presented at the Semi-Annual Meeting of the Society in June, 1935. At the present time the committee is reviewing several papers for presentation at the Annual Meeting of the Society in December, 1935. These papers are on the correlation of spring-wire bending, torsion-fatigue tests, and maximum shearing stress in an eccentrically loaded helical spring of circular wire. In February, 1935, Dr. W. G. Brombacher at the National Bureau of Standards completed and distributed the tenth supplement to the Committee's Bibliography on Mechanical Springs.

*Effect of Temperature on Properties of Metals*, H. J. French, Chairman (Joint Committee with the American Society for Testing Materials). Two meetings of the joint committee were held during the year in December and June and meetings of the subcommittees as required.

During the calendar year 1934, an additional contribution of $3000 to the Joint Committee's funds was received from Engineering Foundation, which made possible continuation of the sponsorship of researches at the Battelle Memorial Institute during the year 1935. Procurement of additional funds for the sponsored researches of the Joint Committee is in the hands of a newly organized Committee II on Finances, the chairmanship of which has been accepted by R. A. Bull.

Work has been continued on the study of embrittlement of austenitic nickel-chromium steels as a result of prolonged exposure to high temperatures and a summary has been prepared. The work in question relates to the progressive changes in toughness of an austenitic steel when exposed for a long period to high temperatures, both with and without stress. Work was initiated on a second project, relating to the interpretation of creep tests, the results of which are now broadly utilized by engineers in determining allowable stresses for high-temperature service.

So many logical questions are still unanswered respecting the behavior of steels under creep, especially in very long periods of time, that the Joint Committee decided to sponsor a program of research at Battelle Institute, in which steels of known creep characteristics (as determined by the customary test of 1000 hr or more) would be used and these steels further tested to durations of two or more years. For one of the materials, K-19 was selected to represent the austenitic type because creep values by the usual orthodox test have already been reported on this identical steel. A pure ferritic steel (K-20) was also selected. The latter is a 0.40 per cent carbon commercial steel of exceptional physical uniformity, furnished gratis by the Bethlehem Steel Company through the good offices of P. E. McKinney. The first progress report on this steel, dated June 2, 1935, was presented to the Joint Committee at the Detroit meeting by Messrs. A. C. Cross and F. B. Dahle. At that time it was voted to continue the 8000 lb per sq in. load at 850 F and also to maintain a sample at 7500 lb per sq in. also at 850 F. The K-19 steel is under test at the load and temperature decided upon as the creep limit under the former tests, i.e., 8345 lb per sq in. and 1200 F.

During the year a number of subcommittees have been at work on other parts of the program and in some cases they have enlisted the cooperation of company and university laboratories. Space available will permit only a list of the committees and the names of their chairmen. "High-Temperature Test Methods," N. L. Mochel, chairman; Subcommittee D, H. J. Kerr, chairman, checking Method E21–34; Subcommittee E, M. S. Northrup, chairman, checking Method E22–34T; Subcommittee F, H. W. Gillett, chairman, work on fatigue suspended for the present; Subcommittee N, J. W. Bolton, chairman, has prepared a report summarizing published data on methods for the determination of wear and seizure at high temperatures; Subcommittee O, Jerome Strauss, chairman, on corrosion of austenitic nickel-chromium steels at elevated temperatures, has prepared a report during the year; and Subcommittee P, H. W. Russell, chairman, organized in March, 1935, to consider the effects of low temperatures on metals.

Committee III on Projects, C. E. MacQuigg, chairman, made a comprehensive report at the June, 1935, meeting of the Joint Committee and pointed out the importance of raising $10,000 from industry in the next two years.

It has been impracticable during the past year to formulate a program acceptable to all interests represented on Committee V on Oil Refinery Problems, but such a program is considered to be necessary before funds can be secured for support of research in this field.

The Joint Committee has been in close touch with the interested committees of the A.S.T.M. and the A.S.M.E. on questions relating to the effect of temperature on the properties of metals and a considerable amount of time has been devoted to these semi-official cooperative projects during the past year.

*Boiler-Feedwater Studies*, C. H. Fellows, Chairman (Joint Committee with the American Boiler Manufacturers Association, American Railway Engineering Association, American Society for Testing Materials, American Water Works Association, and Edison Electric Institute). During the period covered by this 1934–1935 annual report the activities of the Joint Research Committee on Boiler Feedwater Studies have been limited to a continuation of the work in which its subcommittees were engaged during the preceding fiscal year.

An important change in the organization of the committee has occurred as the result of the resignation of S. T. Powell as chairman. Early in the past decade Mr. Powell perceived the importance of extending the knowledge of the industry in the reactions between water and steel under the conditions obtaining as the temperature and pressure of boiler operation increased and organized the joint research committee. With the aid of leaders in the industries vitally interested in these studies, with whom he associated himself, a comprehensive program of research was outlined. Not all phases of the general problem were studied at once; but emphasis was laid first on methods of water analysis and on a study to determine the cause of foaming and priming. The interest stimulated by Mr. Powell's leadership, however, has in the past ten years, advanced in a remarkable manner our knowledge of the reactions occurring within industrial water itself and between it and boiler metal under the conditions of association in modern steam power plants. It was, accordingly, with considerable regret that the members of the Executive Committee acceded to Mr. Powell's wishes and allowed him to relinquish the chairmanship.

The following officers were elected by the executive committee at its meeting in Cincinnati in May of this year to carry on the work of the joint research committee: C. H. Fellows of The Detroit Edison Company, chairman; R. C. Bardwell of The Chesapeake & Ohio Railway Company, vice-chairman; and J. B. Romer of The Babcock & Wilcox Company, secretary. These officers are planning a reorganization of the joint research committee in an effort to stimulate increased financial interest in its work and, at the same time, to further the objectives originally drawn up.

During the past year the work of the Subcommittee on Methods of Boiler Water Analysis was continued at the University of Michigan. A progress report on the incompleted research program concerning methods for determining dissolved oxygen was presented before a session on Boiler Water at the Annual Meeting of the American Water Works Association at Cincinnati in June, 1935, by C. H. Fellows, then chairman of the subcommittee. The research work on the determination of dissolved oxygen undertaken by this technical committee has served to stimulate a number of other investigators in this field. As a result M. C. Schwartz and W. B. Gurney, J. D. Yoder and his associates, D. O. Lima, and others have published results of investigations in this field. The future work of this committee will be under the direction of Prof. A. H. White of the University of Michigan. Professor White has accepted the invitation of the Executive Committee to undertake the chairmanship of this group, which was made vacant when its former chairman was elected to the chairmanship of the joint committee.

The work of the Subcommittee on Zeolite Softeners, Internal Treatment, Priming and Foaming, Electrolytic Scale Prevention under Prof. C. W. Foulk dealing primarily with the causes and prevention of foaming and priming, has been temporarily discontinued. It is planned, however, that this work will be resumed during the coming year.

The work of the Subcommittee on Alkalinity and Sulphate Relations in Boiler-Water Salines, under the direction of J. H. Walker as chairman, has progressed to an important extent during the past

year. W. C. Schroeder has been actively engaged on this project since its inception under the direction of E. P. Partridge at the New Brunswick Station of the U. S. Bureau of Mines. The original objectives have been reached and a report covering this research will be presented at the coming Annual Meeting of the A.S.M.E.

In addition to this completed study, Mr. Walker's committee has initiated a more basic research on the phenomenon of caustic embrittlement. Through the continued prosecution of these studies it is anticipated that many new and important data will be disclosed regarding this subject, permitting a clearer understanding of its development and prevention.

*Condenser Tubes*, A. E. White, Chairman. The results of the work of the Special Research Committee during the year 1934 were coordinated and presented at a meeting of the Committee held during the Annual Meeting of the Society in December, 1934. This report included the progress of short-time methods of corrosion testing of condenser-tube alloys, particularly, by methods of impingement attack and by the use of experimental condensers operating under controlled conditions. This latter work included a comparison of the effect of circulating-water velocity on the corrosion rate of the tubes. Research work on a modified form of apparatus for impingement testing was presented for further investigation and calibration with comparative tube life in service.

Some rather well-defined cases of corrosion in condenser tubes caused by the presence of foreign matter within the tube were shown. Conjecture regarding the effect of foreign matter on tube life is a matter of long standing, however, very few concrete cases taken from service have been available.

A rather comprehensive survey of the experience in service of a number of the newer tube alloys were made. The use of the newer alloys has been increasing steadily. They apparently have a very definite field, at least in certain places, where the tube life of the older alloys has been short.

During 1935 the committee has continued its development of standard methods for corrosion testing and will include in its December, 1935, report a discussion of causes of end corrosion and improved methods for prolonging tube life in condensers where end corrosion is a serious problem.

*Boiler-Furnace Refractories*, W. A. Carter, Chairman. During the past year there has been little progress because of lack of funds. However, some laboratory work on the equilibrium diagram for the alumina-lime-silica-iron oxide system has been continued at the National Bureau of Standards. In addition, the chairman has endeavored to get some help from co-members of the A.S.T.M. Committee C-8 on Refractories to carry on the laboratory slag-test program that the committee was forced to discontinue at the University of Illinois because of lack of funds. The prospects of getting this project under way in the near future are, however, encouraging.

*Absorption of Radiant Heat in Boiler Furnaces*, W. J. Wohlenberg, Chairman. The Society authorized the appointment of a special research committee on absorption of radiant heat in boiler furnaces early in 1928. In 1930 a fellowship was established under the direction of Professor Wohlenberg and financed by The Superheater Company in order to study the problem from both the experimental and theoretical points of view. The experimental work was to consist of radiation and temperature measurements in boiler furnaces together with other data necessary for establishing the energy distribution, the particular furnaces in which the measurements were to be taken to be selected after a study as to type and convenience of arrangements for obtaining the information desired. These tests were carried out on ten boilers in different power plants in the United States and involve stokers, pulverized-fuel, oil, and gas firing with various combinations of refractory protected and water-cooled furnaces.

When the results of the investigations were presented to the Committee at its December 5, 1934, meeting, it was decided to present this information to the Society in the form of one or more papers and to further recommend that one session of the 1935 Annual Meeting be devoted exclusively to this subject. Such a session is now being sponsored by the Fuels Division and the Subcommittee on Heat Transfer of the Process Division. The papers to be read at this session have been written by W. J. Wohlenberg, W. H. Armacost, C. W. Gordon, and H. F. Mullikin.

*Velocity Measurement of Fluid Flow*, W. F. Durand, Chairman. A variant method for determining air velocity in a pipe using sound impulses rather than wave trains of definite frequency was investigated. The method consists in starting a sound pulse at a point in the pipe carrying the air and adjusting a length measured upstream against a fixed length measured downstream so that the pulse arrives at the two terminations simultaneously. The method employed for determining simultaneity consisted in converting the arrived sound pulses to electrical pulses by means of telephone receivers and applying the electrical pulses to the grids of two gas-type electronic tubes so coupled that the tube receiving the impulse registers and thereby prevents the other tube from registering. By manipulating the length of one of the sound paths, either one or the other electronic tubes can be made to register for a steady state of fluid flow. This enables the path length of simultaneous sound-pulse arrival to be determined. The difference in path length of the adjustable arm over that determined when the fluid is at rest, is a measure of the fluid velocity.

The method was devised to avoid the effect of sound reflections in the pipe which hitherto have been found extremely troublesome. This scheme depends for its operation only on the first pulse arriving, the apparatus thereafter being rendered automatically inoperative for a time sufficient to allow sound disturbances to subside.

The scheme was found to work successfully over the fluid-velocity range possible with the apparatus at hand, namely velocities from 1 to 22 ft per sec. The fluid velocities were checked by means of a gasometer and stopwatch. The reproducibility of velocity readings obtained with the acoustic method was superior to that obtained with the gasometer and the average velocities determined by the two methods agreed to within one per cent.

Measurements were made of air velocity in two different pipes, the first an iron conduit of 1.37 in. internal diameter, the second a brass tube with an internal diameter of 0.293 in. Fluid velocities from 1 to 7 ft per sec could be produced in the large pipe, and velocities up to 22 ft per sec in the small tube.

Fluid turbulence apparently does not affect the operation of the device in a significant way, at least for the velocities and pipe diameters investigated. Also it was found that it was not necessary to use an arbitrary correction factor to reconcile the velocity values obtained by the acoustic method with those obtained with the gasometer standard. Accordingly it appears that the acoustic method may be regarded as an absolute method yielding correct velocity values from simple length measurements and the velocity of acoustic propagation in the fluid medium.

*Strength of Vessels Under External Pressure*, W. D. Halsey, Chairman. The special research committee is at present investigating the possibilities of furnishing simple means for computing the dimensions and stresses of vessels under external pressure constructed of materials other than steel and also of steel vessels but at elevated temperatures. Whereas it would be possible to provide charts for the calculation of such vessels, the preparation of such charts would entail an enormous amount of work and it is hoped that a more simple means may be developed.

The committee expects to furnish also within the near future a discussion of the underlying principles of the report it has already published and which has been incorporated as a section of the A.S.M.E. Code for Unfired Pressure Vessels. In the meantime, it is undertaking to answer questions raised by the membership regarding the application of the rules given in its first report.

*Wire Rope*, W. H. Fulweiler, Chairman. The National Bureau of Standards has completed the report of the tests on some 200 samples of discarded wire rope. This report shows the close relationship between wear and broken wires in a rope and its remaining strength. Publication of the report is being delayed until after its findings have been checked by wire-rope inspectors in the field.

*Heavy-Duty Anti-Friction Bearings*, W. Trinks, Chairman. During the year the committee has continued its search through published and privately obtained data for additional findings relating to the various phases of its research program. While some additional information has been obtained, no developments have been brought to light which require revision or immediate amplification of the committee's previous reports. The report summarizing the results of the committee's experimental investigation has just been published as a separate pamphlet under the title "Roll-Neck Bearings."

In so far as the committee's plans are concerned, the immediate future may be characterized as a period of watchful waiting, to be continued until foreign or private investigators unearth new data, or until demand arises for resumption of an active program by the committee.

*Rotary Drilling of Oil Wells*, D. D. Trax, Chairman. The activity of the Special Research Committee on Rotary Drilling of Oil Wells has been limited this year to a recasting of the report on performance and efficiency of gas-electric prime movers for rotary drilling which was presented at the Petroleum Division meeting held in Tulsa in May, 1934. When the report is completed the committee proposes to recommend its publication as a separate pamphlet.

*Critical-Pressure Steam Boilers*, A. A. Potter, Chairman. The major portion of the year was devoted to a study of the viscosity of water and of steam. There are no data available for the viscosity of water at temperatures above 320 F and in the case of steam the values for viscosity above atmospheric pressure are not known with sufficient accuracy. Up-to-date data are available on the viscosity of water from 212 F up to and including the critical temperature.

Interesting results have also been secured on the effect of pressure on the viscosity of subcooled water.

The viscosity of steam has been investigated since June, 1935, at pressures up to 3500 lb per sq in. and at temperatures up to 1000 F. The results of the investigations of the viscosity of water and of steam under the previously mentioned conditions will be presented in a paper at the coming Annual Meeting. The plans for the next year include a study of dissociation at high pressures and temperatures.

*Sampling of Pulverized Fuel in Moving Gas Streams*, K. M. Irwin, Chairman. At its meeting in New York in December, 1934, the committee decided not to solicit funds to cover further laboratory tests but to limit the committee's activities to an inquiry from the present users of pulverized-fuel equipment relative to the methods they are now using to obtain pulverized-fuel samples and also to attempt to secure an expression of opinion from them as to the relative accuracy of the methods which are being employed.

A questionnaire is in preparation for this purpose which has been reviewed by a few members of the special research committee. It is hoped that before the end of 1935, final approval on the form of the questionnaire will be reached and that during the next year the committee will be successful in collecting a considerable amount of information.

*Cottonseed Processing*, W. R. Woolrich, Chairman. The University of Tennessee, the Tri-State Cotton Oil Mill Superintendents Association, the Tennessee Valley Authority, the Engineering Foundation and the A.S.M.E. Special Research Committee are cooperating in this research program. Through laboratory investigation at the University, fundamental and basic facts relative to the processing of cottonseed are uncovered and proved. When necessary, experimental equipment is built and trial runs made to determine the value of new processes or products. A progress report was presented to the Society during the year at the 1934 Annual Meeting, by Chairman Woolrich.

Future plans involve the finding of more new uses for the cottonseed bi-products and the extension of the research program into the demonstration stage, especially that of a continuous cooker of the type which has been developed within the laboratory.

*Inactive Committees.* Five of the twenty-four special research committees on Elevator Safeties, Worm Gears, Measures of Management, Removal of Ash as Molten Slag from Powdered-Coal Furnaces, and Automatic Oil Pipe Line Pumping Stations have been inactive during the past year for financial and other reasons.

Respectfully submitted,

G. M. Eaton, *Chairman*
D. B. Bullard H. A. Johnson
N. E. Funk C. R. Richards

## STANDARDIZATION

A review of the year's activity among the standardization committees sponsored by the Society reveals a commendable amount of progress and the Standardization Committee takes considerable pleasure and pride in reporting the results accomplished. Within the fiscal year just closed (October 1, 1934, to October 1, 1935) eight standards were completed and presented to the American Standards Association for approval. These standards are as follows:

- Shafting and Stock Keys
- Screw Threads
- Adjusted Pressure Ratings for Steel Flanges and Flanged Fittings
- Jig Bushings
- Drawings and Drafting-Room Practice
- Graphical Symbols
- Code for Pressure Piping
- Hose Coupling Screw Threads
- Wrought-Iron and Wrought-Steel Pipe
- Cast-Iron Soil Pipe and Fittings

In the paragraphs which follow will be found brief statements covering the year's progress of every committee that has been active during that period. For the convenience of reference the present status of the several projects for which the Society holds sponsorship or joint sponsorship under the A.S.A. procedure is indicated also by classifying them under the following six heads that represent definite steps in that procedure but in reverse order according to time: (1) Before the A.S.A. for final approval and released for publication; (2) proposed standard before sponsor bodies; (3) revised proposal before sectional committee; (4) completion of report by subcommittee; (5) review of comments by subcommittee; and (6) development of proposal by subcommittee.

### (1) Before the A.S.A. for Final Approval and Released for Publication

*Shafting and Stock Keys*, C. M. Chapman, Chairman. Four standards formerly approved by the A.S.A., B17a—1924, B17b—1925, B17d—1927, and B17e—1927 were revised with additions and republished in one pamphlet after approval in December, 1934.

*Screw Threads*, R. E. Flanders, Chairman. The two sponsor bodies, the Society of Automotive Engineers and The American Society of Mechanical Engineers approved the first revision of the American Standard for Screw Threads, originally published in 1924, in February, 1935, and November, 1934, respectively. Accordingly, in March, the proposal was transmitted to the American Standards Association for final approval and designation as an American Standard. This designation was given in April, 1935, and the standard known as B1.1—1935 is now available in pamphlet form.

*Adjusted Pressure Ratings for Steel Flanges and Flanged Fittings*, A. M. Houser, Chairman. The letter-ballot vote of the members of the Sectional Committee on the Standardization of Pipe Flanges and Fittings was completed in March, 1935, and resulted in a favorable recommendation in regard to the revised tables for pressure-temperature ratings that were prepared by Subcommittee No. 4 on Materials and Stresses to replace Table 1 in the American Standard for Steel-Flanged Fittings and Companion Flanges (B16e—1932). The Heating, Piping, and Air Conditioning Contractors National Association, one of the sponsors, approved this proposal in April, 1935, while the other two sponsors, the Manufacturers Standardization Society of the Valve and Fittings Industry and The American Society of Mechanical Engineers gave their approval in May, 1935. The proposal was placed before the A.S.A. for approval in May, 1935. This was granted in September.

*Jig Bushings*, F. S. Walters, Chairman. The National Machine-Tool Builders Association, the Society of Automotive Engineers, and The American Society of Mechanical Engineers, as sponsors, approved the proposed American Standard for Jig Bushings during the past year, and it was presented to the American Standards Association for final approval in March, 1935. This approval was given in April and this new American Standard (B5.6—1935) is now available.

*Drawings and Drafting-Room Practice*, F. DeR. Furman, Chairman. The American Society of Mechanical Engineers as one of the sponsors for the proposed American Standard for Drawings and Drafting-Room Practice signified its approval of this proposal in February, 1935. Approval of the other sponsor, the Society for the Promotion of Engineering Education, was given the previous June. It was transmitted to the American Standards Association in March and its approval and designation as an American Standard was given in May. This standard therefore, is available now in pamphlet form with the serial designation 214.1—1935.

*Graphical Symbols*, T. E. French, Chairman. The proposed American Standard for Graphical Symbols was approved by The American Society of Mechanical Engineers as sponsor in May, 1935. The other joint sponsor, the Society for the Promotion of Engineering Education gave its approval in June, 1934, contingent on approval by the sectional committee and the A.S.M.E. However, several suggestions made by certain members of the Sectional Committee on the Standardization of Drawings and Drafting-Room Practice at the time of the letter-ballot vote made necessary a further review of a number of the proposed standard symbols. Accordingly, in June, 1935, a summary of these suggestions was sent to the entire membership of the sectional committee for vote by letter ballot. The changes which were approved by this ballot were included in the proposed standard submitted to the A.S.A. in September, 1935.

*Code for Pressure Piping*, E. B. Ricketts, Chairman. The letter-ballot vote of the members of the Sectional Committee on Code for Pressure Piping was completed in December, 1934. The Code was then submitted to The American Society of Mechanical Engineers for approval in its capacity as sole sponsor. This approval was given in February, 1935, and in March the proposed American Tentative Standard Code for Pressure Piping was presented to the American Standards Association for final approval. Favorable action was announced in June, and the code was made available immediately in pamphlet form with the number B31—1935.

*Wrought-Iron and Wrought-Steel Pipe*, H. H. Morgan, Chairman. In November, 1934, the American Society of Mechanical Engineers, as one of the two joint sponsors, gave its approval to the proposed American Tentative Standard for Wrought-Iron and Wrought-Steel Pipe, and The American Society for Testing Materials, the other sponsor for this project, gave its approval in February, 1935. While the proposal was presented to the A.S.A. in March, 1935, some delay in securing its approval has resulted from a disagreement concerning slight changes which had been made by the editing committee in the wording of Paragraph 3 of the introductory notes.

*Hose Coupling Screw Threads*, H. W. Bearce, Chairman. Objec-

tions raised during A.S.A. vote necessitated another meeting of Sectional committee. Standard finally approved and published in July, 1935.

*Cast-Iron Soil Pipe and Fittings*, J. J. Crotty, Chairman. The proposed American Standard for Cast-Iron Soil Pipe was completed in April, 1935; it was submitted to the members of the Sectional Committee on Plumbing Equipment for approval by letter ballot in May and was presented to the two sponsor societies in July, 1935. The American Society of Sanitary Engineering and The American Society of Mechanical Engineers, gave their approval to the proposed standard in August, and in the same month it was transmitted to the A.S.A. for final approval and designation as an American Standard. W. C. Groeniger is chairman of the Sectional Committee.

#### (2) Proposed Standard Before Sponsor Bodies

*Brass Fittings for Flared Copper Tubes*, F. L. Riggin, Chairman. The development of a standard for brass fittings for flared copper water tubes was initiated by a subgroup composed principally of manufacturers and in 1930 a tentative draft was submitted for review to the members of Subcommittee No. 7 of the Sectional Committee on Plumbing Equipment. After some revision, the proposed standard was distributed broadly to industry for criticism in February, 1931. Then followed considerable correspondence between the members of the subcommittee and groups in the industry. Finally in March, 1934, it was approved in revised form by Subcommittee No. 7 and submitted to the sectional committee for vote on approval by letter ballot. This vote was favorable and in September, 1935, the proposed standard was submitted to the sponsor bodies, the American Society of Sanitary Engineering and The American Society of Mechanical Engineers for approval and transmission to the A.S.A.

*Socket Set Screws and Socket-Head Cap Screws*, H. Koester, Chairman. In April, 1935, the final draft of the proposed American Standard for Socket Set Screws and Socket-Head Cap Screws was released by Subcommittee No. 9 to the Sectional Committee on the Standardization of Bolt, Nut, and Rivet Proportions for vote on approval by letter ballot. This vote was favorable and the proposed standard was submitted to the two sponsors, the Society of Automotive Engineers and The American Society of Mechanical Engineers in August, 1935.

#### (3) Revised Proposal Before Sectional Committee

*Ammonia Flanged Fittings and Companion Flanges*, W. R. Kremer, Chairman. The letter-ballot vote of the members of the Sectional Committee on the Standardization of Pipe Flanges and Fittings on the proposed American Tentative Standard for Ammonia Flanged Fittings and Companion Flanges was completed in October, 1934. The results of this ballot indicated, however, that certain extensive changes and additions were desired by the members of the sectional committee. The officers of the committee, after considerable correspondence prepared a revised draft of the proposal and resubmitted it to the members of the sectional committee in September, 1935, for vote on approval by letter ballot.

#### (4) Completion of Report by Subcommittee

*Taper Pipe Threads*, S. B. Terry, Chairman. Subcommittee No. 2 completed its revision of the American Standard for Pipe Threads (B2—1919) in September, 1935. As the next step in the development of the proposed revision, it will be submitted to the members of the Sectional Committee on Pipe Threads for approval by letter-ballot vote.

*Machine Tapers*, F. S. Blackall, Jr., Chairman. The final draft of the proposed American Standard for Machine Tapers with certain minor corrections and changes was approved by Technical Committee No. 3 of the Sectional Committee on Small Tools and Machine Tool Elements at its meeting in December, 1934. After final checking of all details, the proposed standard will be mailed to the members of the sectional committee for vote by letter ballot.

*Spindle Noses and Collets*, J. E. Lovely, Chairman. Technical Committee No. 4 on Spindle Noses and Collets of the Sectional Committee on Small Tools and Machine-Tool Elements was organized in December, 1928. It cooperated with Technical Committee No. 11 in the preparation of a draft standard on Spindle Noses and Chucks distributed to industry for comment in May, 1930.

However, as a result of suggestions made at numerous conferences with members of the industry, Technical Committee No. 4 in March, 1931, drew up a revised draft of this proposal dealing only with lathe-spindle noses. In October, 1932, this draft was approved by the lathe groups of the National Machine Tool Builders Association.

During 1933, the committee carried on tests on new forms of spindle noses. Subsequently sufficient experience with the proposed standard type of spindle nose has been had and recorded, and the new designs have met with such universal approval by industry that in October, 1934, copies of the proposal in its final form covering spindle noses for turret lathes and automatic lathes were sent to the members of the Technical Committee. In March, 1935, the Technical Committee released this proposed standard to the Nomenclature Committee for review. Following this review it will be submitted to the members of the Sectional Committee for vote by letter ballot.

*Chucks and Chuck Jaws*, J. E. Lovely, Chairman. Work on the preparation of a proposed standard for Chucks and Chuck Jaws was begun in December, 1928, with the organization of Technical Committee No. 11. Subsequently, Technical Committee No. 11 collaborated with Technical Committee No. 4 on Spindle Noses and Collets in preparing a draft standard on Spindle Noses and Chucks. In May, 1930, these committees distributed to industry for comment a joint proposal entitled proposed American Standard for Spindle Noses and Chucks. The next year a revised draft of this proposal dealing only with chucks and chuck jaws and based on the comments received as a result of the previous canvass of industry was circulated to industry for further comment.

After extensive correspondence relating to the adjustment of various changes and corrections suggested by the manufacturers of chucks, Technical Committee No. 11 completed the final draft of the proposed standard and released it to the Sectional Committee in March, 1935. Following review by Technical Committee No. 17 on Nomenclature, it will be submitted to the members of the Sectional Committee for vote by letter ballot.

*Circular Forming Tools and Holders*, W. C. Mueller, Chairman. Work on a proposed standard for circular forming tools and holders for automatic screw machines was begun in 1931 by Technical Committee No. 10. During the course of the next three years, four questionnaires were distributed to industry for criticism and comment and the suggestions received were, incorporated as far as possible, in successive revisions of the proposed standard. In August, 1934, a final draft of the proposal was sent to the members of the Technical Committee, and in November, 1934, it was released to the Sectional Committee.

Technical Committee No. 17 was asked to develop the nomenclature for this standard and when this is completed the proposed standard will be sent to the members of the Sectional Committee for vote on approval by letter ballot.

#### (5) Review of Comments by Subcommittee

*Inspection of Gears*, F. W. England, Chairman. In May, 1935, the Recommended Practice of the American Gear Manufacturers' Association for Inspection of Gears was mailed to a selected list of users of gears with a request for their criticism and comment. Subcommittee No. 9 of the Sectional Committee on the Standardization of Gears proposes that these rules form the basis of the American Standard for the Inspection of Gears. The replies which were received are now in the hands of the subcommittee for study.

*Large Rivets*, R. N. S. Baker, Chairman. As a result of the meeting of Subcommittee No. 1 on Large and Small Rivets held in New York in December, 1934, the proposed American Standard for Large Rivets was broadly distributed in June, 1935, for criticism and constructive suggestions. The replies received are now in the hands of the subcommittee.

*Plain Washers*, C. W. Squier, Chairman. During the past year a tentative draft of the proposed American Standard for Plain Washers for use with American Standard Bolt Heads and Nuts was completed by Subcommittee No. 1 and distributed broadly for the general criticism and comment of industry. Consideration is now being given to the replies received.

*Speeds of Machinery*, A. E. Hall, Chairman. The special subgroup appointed to study the comments received from industry following the distribution of copies of a tentative draft of the proposed American Standard for Machine Speeds held a meeting in New York, in April, 1935. A revised draft of the proposal based on the subgroup's recommendations is now being prepared.

*Traps*, A. R. McGonegal, Chairman. In February, 1935, a draft of the proposed American Standard for Traps for use with plumbing fixtures was distributed to industry for review and comment. Subcommittee No. 5 of the Sectional Committee on Plumbing Equipment is now reviewing the replies which were transmitted to the chairman late in April. These suggestions will form the basis of a further revision of this proposal.

*Pressure and Vacuum Gages*, M. D. Engle, Chairman. Subcommittee No. 3 on Gage Sizes and Mounting Dimensions, H. B. Reynolds, chairman, and Subcommittee No. 4 on Accuracy and Test Methods, O. J. Hodge, chairman, are reviewing letters received as a result of the general distribution of their parts of the proposed standard to industry for criticism and comment. Section 3 was mailed in November, 1934, and Section 4 was distributed in April, 1935. There is a possibility that all of the three sections of this proposed

standard will be ready early this fall for the editing committee, which is to mold them into a unified whole.

(6) Development of Proposal by Subcommittee

*Round Unslotted Head Bolts.* At the December, 1934, Meeting of Subcommittee No. 5, a proposed revision of the American Tentative Standard for Round Unslotted Head Bolts published in 1928 (B18e—1928) was approved. Draft copies of this proposed revision had been distributed previously to the committee members and others interested for their consideration. It was found necessary to prepare a new table for thread lengths, copies of which were distributed to the members of the committee in July, 1935. If satisfactory, this table will be incorporated in the proposed revision which then will be circulated to industry at large for criticism and comment.

*T-Slots,* Erik Oberg, Chairman. Technical Committee No. 1 of the Sectional Committee on Small Tools and Machine-Tool Elements completed its report on the "Nomenclature and Glossary of Terms for T-Slots," in May, 1935. This report is now in the hands of Technical Committee No. 17 on Nomenclature after which this supplement to B5a—1927 will be submitted to the members of the sectional committee for approval.

*Punch-Press Tools,* D. M. Palmer, Chairman. The reorganized Technical Committee No. 9 on Punch-Press Tools held a meeting in Detroit in February, 1935, at which substantial progress was made toward the completion of a tentative draft of the committee's proposal intended to cover certain parts of all classes of die sets considered suitable subjects for standardization.

*Single-Point Cutting Tools,* F. H. Colvin, Chairman. Technical Committee No. 19 which was organized in December, 1933, completed its report on the nomenclature for single-point tools in May, 1935. This report will be submitted shortly to the members of the sectional committee for approval.

*Preferred Practice in Graphic Presentation,* A. H. Richardson, Chairman. Subcommittee No. 3 of the Sectional Committee on Standards for Graphic Presentation at its meeting held in New York in June, 1935, adopted, with a few minor changes, a tentative draft of a code for preferred practice in graphic presentation which had been in course of preparation for a number of years. The subcommittee plans to have about five hundred copies of this proposed code printed for preliminary review, the expense to be covered by sales to the public. This would be in the nature of a trial edition which thus could be tested in practice and, if found to be satisfactory, presented to The American Society of Mechanical Engineers as sponsor society for approval and transmission to the American Standards Association.

*Engineering and Scientific Graphs,* W. A. Shewhart, Chairman. The special subgroup of Subcommittee No. 4 appointed in April, 1934, to prepare a standard nomenclature for the shapes of curves and plots, under the chairmanship of E. T. Cope, completed its report in May, 1935, and distributed copies of it to the members of the subcommittee in June of this year for examination and comment.

The special subgroup under the chairmanship of H. F. Dodge appointed also in April, 1934, held a meeting in December of that year to consider a preliminary draft of a brochure on "Engineering and Scientific Graphs for Publications." Consideration was given also at this meeting to an outline of the subgroup's report submitted by Messrs. Stone and Hanscom. Three subsequent meetings were held in January, February, and April and the suggestions developed at these meetings have been incorporated in a redraft of the proposal.

*Tolerance Systems,* R. E. W. Harrison, Chairman. Subcommittee No. 1 of the Sectional Committee on Allowances and Tolerances for Cylindrical Parts and Limit Gages held a meeting in New York in December, 1934. At this meeting a full discussion of the differences between the present standard (B4.1—1925) and the I.S.A. Standard with special reference to ranges and classes of fit took place. D. R. Miller, a member of the committee, then was requested to prepare a set of ranges and tolerances following the general trend of B4.1—1925 and the I.S.A. standard but with the fewest possible and widest practical ranges. This task was completed and copies of the report were distributed to the members of the subcommittee in June, 1935.

*Cut and Ground Thread Taps,* C. M. Pond, Chairman. At its meeting in December, 1934, Technical Committee No. 12 discussed and approved revisions of the American Standard for Cut and Ground Thread Taps (B5e—1930). This revision is based on comments and suggestions received as a result of the distribution of a tentatively revised draft to industry at large in May, 1934. After approval by the members of the Sectional Committee on Small Tools and Machine-Tool Elements this revision will be submitted to the sponsor societies and the American Standards Association.

*Gasoline, Oil, and Grease Separators,* J. J. Crotty, Chairman. Meetings of Subcommittee No. 9 were held in November, 1934, and March, 1935, and good progress was made toward the completion of the first draft of a proposed American Standard for Gasoline, Oil, and Grease Separators. At the November, 1934, meeting, a report on the "Recommended Use for Oil Separators and Their Construction" was presented and discussed. There is now before the subcommittee for its consideration a draft of a proposed standard ordinance to regulate the handling, storage, transportation, and disposition of waste oils and grease resulting from the use and operation, cleaning, repairing, or servicing of vehicles, machinery, or appliances of any kind. This project is part of the program of the Sectional Committee on Plumbing Equipment.

*Iron and Steel Bars,* F. H. Frankland, Chairman. The Sectional Committee on the Standardization of Stock Sizes, Shapes, and Lengths for Hot-Rolled and Cold-Finished Iron and Steel Bars held a meeting in New York on April 23, 1935. The committee discussed seriously the need for this standard and the form which it should take. It was finally decided that the gathering together of the several present trade practices within the scope of the committee's work and the placing them in form for review and approval by the American Standards Association would render a useful service.

Accordingly, certain members of the committee agreed to supply a list of shapes, sizes, lengths, and tolerances of hot-rolled bars together with similar data for hot-rolled reinforcing bars. Another group offered to supply the same data for cold-finished steel bars. It was then decided that, when this material had been assembled and worked up into the form of a standard, it should be distributed to the members of the Sectional Committee as a tentative proposal.

*Classification and Designation of Surface Qualities,* C. G. Mettler, Chairman. Subcommittee No. 1 on Standardization of Surfaces Produced by Tools and Abrasives, J. Cetrule, chairman, held a meeting in December, 1934, at which a comprehensive report of Subgroup No. 2 on Machine Surfaces Produced by Tools, of which J. S. Chafee is chairman, was read and discussed. As a result of this discussion the subgroup was assigned further duties and from subsequent correspondence with Mr. Chafee it is expected that a report will be forthcoming shortly.

In December, 1934, a meeting was held also by Subcommittee No. 5 on Ways, Means, and Apparatus for Measuring Quality of Surface, J. R. Weaver, Chairman, at which Prof. F. A. Firestone's report on definitions and notation for measurement of surface quality was read and discussed. At this meeting consideration was given also to a program of experimental work which had been outlined in a letter sent out by the secretary of the subcommittee the previous spring and, as a result of the discussion, a subgroup headed by G. A. Bouvier, was appointed to carry out that part of the program relating to the measurement, by various methods, of samples of representative surfaces.

*Furnaces,* C. E. Bronson, Temporary Chairman. Upon the recommendation of the A.S.M.E. Pure Air Committee together with a large number of representative and interested organizations, a Sectional Committee on the Unification of Rules for Dimensioning of Furnaces for Burning Solid Fuel was organized in June, 1933, in Chicago under the procedure of the American Standards Association. The present economic conditions have operated to delay the completion of the personnel of this sectional committee and the five subcommittees which were authorized by the sectional committee at its first meeting. Mr. Bronson gives assurance, however, that this task is now nearly completed.

As a matter of record, the following statistics are given for the purpose of indicating the extent of this activity and the number of persons having a part in it. Number of Sectional Committees 31; number of subcommittees and subgroups 273; number of committee members, members of A.S.M.E. 371, non-members 812; number of committee meetings held in year, 24; number of cooperating organizations, 206.

Respectfully submitted,

C. W. Spicer, *Chairman*
Alfred Iddles — Walter Samans
L. A. Cornelius — O. A. Leutwiler

## POWER TEST CODES

The Committee on Power Test Codes takes pleasure in reporting that during the fiscal year 1934–1935 one new test code and one revised code were completed, approved, and published while two new sections of Instruments and Apparatus and one revised section were completed and approved by the Council. A more detailed statement covering this activity is given in the following paragraphs.

Items of General Interest

*Election of Acting Chairman of Power Test Codes Committee.* In recognition of the service which Dr. Robert H. Fernald had so willingly rendered the main Committee during the period of Dr. Low's illness, the committee requested him at its December, 1934,

meeting to serve as its acting chairman until such a time as Chairman Low will be able again to take his place.

*Btu per Hour Equivalents of Horsepower and Kilowatt.* In a comment on the November, 1934, draft of the proposed revision of the Test Code for Steam-Condensing Apparatus attention was called to the disagreement between the values there given for the Btu per hour equivalents for "horsepower" and the "kilowatt," and the similar values given in the Keenan Steam Tables. The constants 2543 and 3413 Btu per hr respectively in the code were taken from the Code on Definitions and Values and those in the Keenan Steam Tables, 2543.1 and 3411.5, are based on the International calorie which was defined at the 1929 International Steam Tables Conference (London) as 1/860 of the International watt-hour.

Since the publication of the Keenan Steam Tables, the National Bureau of Standards has adjusted the basic values of its electrical standards to agree with the International values and the American Standards Association has accepted similar modifications.

In view of these developments which have taken place since the Code on Definitions and Values was issued in June, 1931, Committee No. 2 on Definitions and Values has been requested to revise its Btu-per-hour equivalents for horsepower and the kilowatt for use in new or revised power-test codes.

*A.S.T.M. Committee on Gaseous Fuels.* Because of the direct interest in this subject of the Power Test Codes Committee No. 3 on Fuels, E. X. Schmidt, a member of that committee was named as its representative on the A.S.T.M. committee, which now has been organized to standardize the nomenclature and the methods of sampling and testing gaseous fuels in so far as they apply to purchases and sales and the requirements of regulatory bodies. Mr. Schmidt has been active in the development of the A.S.M.E. Power Test Code for Gaseous Fuels.

*Committee Meetings.* As a matter of record it should be stated that the following committees held regularly called meetings during the past twelve months: Power Test Codes Committee, three meetings, October, December, and April; Committee No. 6 on Steam Turbines; Committee No. 10 Subcommittee on Fans; Committee No. 11 on Complete Steam Power Plants; Committee No. 18 on Hydraulic Prime Movers; special Subcommittee on Measurement of Fluid Flow of Committee No. 19 on Instruments and Apparatus; and Committee No. 21 on Dust-Separating Apparatus.

### Committee Progress

*Fuels.* Committee No. 3 on Fuels, W. J. Wohlenberg, Chairman, completed its review of the preliminary draft of the Test Code for Gaseous Fuels in November, 1934. The code is now in shape for distribution to a selected list of individuals and firms for criticism and comment.

*Reciprocating Steam Engines.* Committee No. 5 on Reciprocating Steam Engines, A. G. Christie, Chairman, completed an extensive revision of the Test Code for Reciprocating Engines and on February 6, 1935, it was approved by the Council and subsequently published in pamphlet form.

*Steam Turbines.* Committee No. 6 on Steam Turbines, C. H. Berry, Chairman, met during the 1934 Annual Meeting of the Society to discuss the voluminous material that had been distributed to the members dealing with the proposed revision of the Test Code for Steam Turbines. A subcommittee of three was appointed at that time to develop the revision of the code. This subcommittee is working effectively and definite progress is being made toward the completion of the revised draft of this test code.

*Centrifugal and Rotary Pumps.* Committee No. 8 on Centrifugal and Rotary Pumps, W. B. Gregory, Chairman, is now considering the advisability of an immediate revision of this code which was approved and published in February, 1928. This step was urged in a communication received from the Hydraulic Institute. In the use of this code as its standard of testing practice, the Institute has realized more and more that it is not altogether adequate and, through the efforts of one of its committees, it has been endeavoring to agree upon certain desirable revisions, and additions, and the standardization of certain of the testing methods and equipment. As the principal purpose of these codes is to serve the practical needs of industry, the Committee, when it has acquainted itself with the exact nature and extent of the changes desired, will begin work on a revised draft.

*Displacement Compressors and Blowers.* Committee No. 9 on Displacement Compressors and Blowers, Paul Diserens, Chairman, is now laying plans for a complete revision of the Test Code for Displacement Compressors and Blowers. Before undertaking this work the committee is awaiting the report of the Instruments and Apparatus Special Subcommittee on the Measurement of Fluid Flow covering rules for the measurement of air flow from a gaging tank into the atmosphere and from the atmosphere into a gaging tank.

*Centrifugal and Turbo-Compressors and Blowers.* Chairman, A. T. Brown, Committee No. 10, reports the publication in pamphlet form in March, 1935, of Part 1 on Compressors and Blowers of the Test Code for Centrifugal Compressors, Exhausters, and Fans.

The Subcommittee on Fans, M. C. Stuart, Chairman, held two meetings within the year, during which the first tentative draft of the Test Code for Fans was outlined. The development of the code has been delayed due to the lack of adequate information and agreement on the standard methods of measuring air. Accordingly, several subgroups have been organized to formulate standard methods for the measurement of air under the conditions to be found in the testing of fans. To provide the necessary data and information investigations are under way at Lehigh University under the direction of Professor Stuart; at Harvard University, under the direction of Professor Marks; and in the laboratories of several of the fan manufacturers. They cover (1) measurement of flow by pitot tube in inlet or discharge ducts; (2) measurement of flow by nozzle in inlet or discharge ducts; and (3) measurement of flow with large chamber by nozzle or orifice. The subcommittee hopes that before the end of another year it will have completed the first tentative draft of the Test Code for Fans.

In order to bring about closer cooperation between the A.S.M.E. committee and the committees of the American Society of Heating and Ventilating Engineers interested in fan testing, Thomas Chester, consulting engineer of Detroit, has been appointed to membership on the committee. Mr. Chester is chairman of the Special Council Committee of the American Society of Heating and Ventilating Engineers, organized to review that Society's Standard Code for Disk and Propeller Fans, Centrifugal Fans and Blowers.

During the two years since the organization of the Subcommittee on Fans it has been consolidating data and information bearing on its work. To develop further some of the ideas which have been advanced it applied for permission to hold a technical session during the 1934 Annual Meeting. This was granted and on Tuesday, December 4, a session was presided over by Willis H. Carrier and papers were presented by L. S. Marks, N. P. Bailey, W. E. Somers, N. C. Ebaugh and R. Whitfield, and M. C. Stuart. So great was the interest in this session that another is being planned for the 1935 Annual Meeting.

*Steam-Condensing Apparatus.* Geo. A. Orrok, Chairman, of Committee No. 12 on Condensers, Water-Heating and Cooling Equipment, reported in December, 1934, the completion of the proposed revision of the Test Code for Steam-Condensing Apparatus. The present revision of the code includes a tentative method for determining the cleanliness factor of condenser tubes. Copies of a tentative draft have been distributed to an extensive selected list of firms and individuals for criticism and comment. As a result of this mailing a number of constructive criticisms of this proposed revision of the code have been received. The duplication of this material was generously arranged for by the Brooklyn Edison Company through P. H. Hardie, secretary and member of Committee No. 12.

*Hydraulic Prime Movers.* E. C. Hutchinson, Chairman of Committee No. 18 on Hydraulic Prime Movers, reports that the committee has completed the drafting of the proposed revision of the Test Code for Hydraulic Prime Movers. The committee held meetings during the annual meetings of the A.S.M.E. and A.S.C.E. which made it possible to reach agreement on all of the controversial points which had been raised in the development of the earlier drafts. Its plans call for the distribution of copies of the code to a selected list of firms and individuals for criticism and comment before it is presented for final approval.

*Instruments and Apparatus.* C. F. Hirshfeld, Chairman, Committee No. 19 on Instruments and Apparatus, reports that the work completed by the committee during the year just closed includes the following sections which were approved for publication, namely: Part 1 on General Considerations (second edition); chapter 2 on Radiation Pyrometers of Part 3 on Temperature Measurement, and Part 15 on Measurement of Surface Areas.

In addition to the above, Committee No. 19 has made good progress toward the completion of Part 2, Pressure Measurement, chapter 4 on Bourdon, Bellows, Diaphragm and Deadweight Gages and chapter 5 on Manometer or Liquid Column Gages; Part 3, Temperature Measurement, chapter 3 on Thermocouple Thermometers; and chapter 4 on Resistance Thermometers.

*Special Subcommittee on Measurement of Fluid Flow.* Inasmuch as there had been some misunderstanding concerning the scope of the work of this special Instruments and Apparatus subcommittee, it was deemed advisable to change its name from Instruments and Apparatus Subcommittee on Flow Nozzles to Instruments and Apparatus Special Subcommittee on Measurement of Fluid Flow.

Due to the urgent need for its reports, the subcommittee is preparing as quickly as possible recommended rules for the measurement of fluid flow which can be made mandatory in the codes prepared by the several individual committees. Preliminary drafts of sections

covering nozzles, orifices, and venturi tubes are being written by the members of the subcommittee. The preliminary draft of the orifice section has been completed and it is expected that similar drafts of the sections on flow nozzles and venturi tubes will be completed within the next few months.

Industry is now being canvassed for funds for the research on flow nozzles which is to be made at the National Bureau of Standards under the auspices of the A.S.M.E. Special Research Committee on Fluid Meters.

As a representative of the American Standards Association, W. A. Carter, Chairman of this special subcommittee, attended the meeting of the International Standards Association Committee No. 30 on the Measurement of Fluid Flow held in Stockholm, Sweden, in September, 1934. He presented the American comments on the I.S.A. Proposal for Measurement of Fluid Flow and urged the inclusion of certain other rules covering the use of nozzles.

A meeting of this special subcommittee was held in New York during the A.S.M.E. Annual Meeting in December, 1934.

*Dust-Separating Apparatus.* The organization meeting of Committee No. 21 on Dust-Separating Apparatus was held on Wednesday, December 5, 1934. At this meeting the members of Committee No. 21 expressed an appreciation of the magnitude of the project and a feeling that several years would elapse before a final report would be forthcoming. M. D. Engle was elected chairman of the committee. The following subcommittees have been appointed to carry forward the program in the development of the Test Code for Dust-Separating Apparatus: (1) on plan and scope; (2) on definitions and terms, bibliography; (3) on collection of data on test methods employed in past and results obtained, equipment available; (4) on the obtaining of representative samples from gas streams carrying dust in suspension; and (5) on separation of the solid matter from the gas of the sample obtained.

### International Cooperation

Through membership on the U. S. National Committee of the International Electrotechnical Commission,[1] the Society, and for it the main Committee on Power Test Codes has been actively engaged in assisting to bring about international agreements on acceptance tests for steam turbines and internal-combustion engines. The Secretariat for the Advisory Committees on Steam Turbines, Internal-Combustion Engines and Hydraulic Turbines is held by the U. S. National Committee of the I.E.C. The Society was represented on this committee this year by Harvey N. Davis, Francis Hodgkinson, and Ely C. Hutchinson, with C. Harold Berry and Paul Diserens serving as alternates.

Respectfully submitted,

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|---|---|
| F. R. Low, *Chairman* | |
| R. H. Fernald, *Acting Chairman* | G. A. Horne |
| C. H. Berry | E. C. Hutchinson |
| A. T. Brown | D. S. Jacobus |
| A. G. Christie | L. F. Moody |
| H. Cooke | H. B. Oatley |
| H. Dahlstrand | G. A. Orrok |
| P. Diserens | R. J. S. Pigott |
| L. Elliott | H. B. Reynolds |
| E. R. Fish | E. B. Ricketts |
| C. F. Hirshfeld | E. N. Trump |
| F. Hodgkinson | W. M. White |
| O. P. Hood | W. J. Wohlenberg |

## PROFESSIONAL CONDUCT

During this past year this Committee has had but one case referred to it. Investigation developed that no charge of unprofessional conduct on the part of a member of the Society was made. Accordingly no action could be taken by this Committee. This case was referred to the Secretary of the Society.

Respectfully submitted,

| | |
|---|---|
| C. G. Spencer, *Chairman* | |
| Edwards R. Fish | E. F. Scott |
| J. H. Herron | Hugo Diemer |

## SAFETY

The Standing Committee on Safety has continued during the past year to promote industrial safety through the activities of the Society and, in reporting the progress made during that period, desires to record first the technical session in the form of a symposium on the engineering aspects of occupational-disease disability, which it sponsored during the 1934 Annual Meeting of the Society. Five papers dealing with different phases of the subject of industrial-disease hazards were read by authorities in each field and were freely discussed. This session drew such a large and interested audience that the committee was encouraged to plan for a similar session at the 1935 Annual Meeting. Good progress has already been made toward the selection of speakers and the subjects of the papers which are to be presented. At the Committee meeting on June 14 it tentatively agreed to the following three divisions of the subject as an outline for the meeting: (*a*) occupational-disease legislation, (*b*) engineering control of occupational-disease hazards, and (*c*) limitations of protective devices and equipment available.

The committee has agreed to act as co-sponsor with the Management Division of the Society for a session on compensation laws which is also to be held during the 1935 Annual Meeting. There are many aspects of this subject in which the committee is directly interested since it holds that there is a close relation between the compensation laws of a state and its laws bearing on disease disability.

*Safety Code for Machinery for Compressing Air*, D. L. Royer, Chairman. During the past year the Sectional Committee on a Safety Code for Machinery for Compressing Air released for criticism and comment two successive drafts of its proposed code which indicates that good progress is being made in its work.

*Safety Code for Cranes, Derricks, and Hoists*, J. C. Wheat, Chairman. No meetings of the Sectional Committee or any of its subcommittees have been held during the past year but from correspondence which this committee has had with Mr. Wheat it has assurances that by the first of the next fiscal year more active work will be resumed toward the completion of this important code which is now in the hands of the editing subcommittee.

*Safety Code for Elevators*, Sullivan W. Jones, Chairman. The Sectional Committee on a Safety Code for Elevators held a meeting on April 26, 1935. This meeting was called to consider certain changes in the American Standard "Safety Code for Elevators" published in 1931 which had been proposed by the Subcommittee on Elevator Research, Interpretations and Recommendations. The subcommittee had held meetings on October 30, 1934, and April 24, 1935.

The proposed American Recommended Practice in the form of an Inspector's Handbook was approved by letter-ballot vote of the Sectional Committee. The committee plans to delay its submittal to the sponsor societies, however, until the new references to the revised Safety Code for Elevators are known.

*Junior Advisory Member.* Upon the recommendation of the Committee Carl Endlein, mechanical engineer connected with the C. J. Tagliabue Manufacturing Company, Brooklyn, N. Y., was appointed by President Flanders as the Junior Adviser to the Safety Committee.

It is with deep regret that the committee reports the death of one of its members, M. H. Christopherson, on September 9, 1935.

Respectfully submitted,

| | |
|---|---|
| W. M. Graff, *Chairman* | H. L. Miner |
| H. H. Judson | J. B. Chalmers |

# Special Committees

## ADVISORY BOARD ON TECHNOLOGY

On December 7, 1934, the Council of The American Society of Mechanical Engineers took the following action:

*Voted:* That the Advisory Board on Technology be established for two years, under the direction of the Council, with functions as stated below:

(1) Assume the responsibility of coordinating the activities of the general meetings and congresses, divisions, research, and publications of the Society.

(2) Assume the responsibility of leadership and initiative with respect to coordination.

(3) Interpret the provisions of the Society's By-Laws concerning the jurisdictions and policies of the several committees represented on the Board.

(4) Review and recommend policies proposed by the several committees for the control of their activities.

(5) Hold at least two meetings each year.

(Note: This Board is to consist of five, a Chairman from the Council, named by the President, and one member of each of the following Standing Committees: Meetings and Program, Professional Divisions, Research, and Publications.)

[1] For Report of A.S.M.E. representatives see page 26.

In the discussion, it was emphasized that the responsibilities of coordination, leadership, and initiative gave the Board a tremendous opportunity to advance the Society's purposes which are embodied in the new By-Laws adopted by Council on December 3, 1934, as follows:

(*a*) Encouraging engineering research, tests and other original work.

(*b*) Encouraging the preparation of original papers on engineering topics.

(*c*) Holding meetings for the presentation and discussion of original papers and participating in international engineering congresses.

(*d*) Publishing papers and reports and disseminating knowledge and experience of value to engineers.

### Personnel

The members of the Board appointed by President Flanders (for a term of two years) and the committees they represent are: Robert I. Rees, Meetings and Program; K. H. Condit, Professional Divisions; S. W. Dudley, Publications; D. B. Bullard, Research; and A. A. Potter, Council, chairman.

### Meetings and Actions

Two meetings of the Board have been held, January 25 and April 18, 1935. Discussions at both meetings centered around problems relating to the coordination of the activities of the committees represented on the Board and to publications. At the second meeting the principle of planning the work of the Society in the technical and educational development of the profession and of members was also discussed.

The view was expressed that every encouragement be given to local sections to send in for consideration by the Committee on Publications the manuscripts of papers presented at their meetings. The committee and the editor were represented as being willing to consider, as in the past, original papers of permanent value for publication in the Transactions, and papers of current interest for publication in *Mechanical Engineering*, which is a record of advancement.

The problems of the Committee on Publications in adequately serving the committees and agencies that provide papers and reports were discussed. Every effort is to be expended in raising the quality of papers and assuring that the papers of permanent value are received sufficiently in advance of meetings to insure adequate review and preprinting so that full discussion will result when the papers are discussed. The principle of budgeting space in the publications to these committees and agencies, as a first step in coordination and planning, was approved.

Relations with the technical press were clarified.

The relation of the professional divisions to the programs of local sections was discussed.

The importance of research as related to other activities of the Society was emphasized, including the opportunity for the research committees and professional divisions to cooperate in preparing bibliographies.

Emphasis upon educational quality should be the major guide and it was considered important to keep the individual member engineering-minded.

A coordinated budget for the committees represented on the Board of Technology was approved.

Respectfully submitted,

A. A. Potter, *Chairman*
D. B. Bullard — S. W. Dudley
K. H. Condit — R. I. Rees

## ADVISORY BOARD ON STANDARDS AND CODES

One of the recommendations of the Special Committee on Policies and Budget of which Harry R. Westcott is chairman, was the establishment of an Advisory Board on Standards and Codes. It is expected that this Board will further coordinate the activities of the four committees in charge of the standardization and code-making activities of the Society. Several conferences of representatives of these activities with members of the Committee on Policies and Budget were held last fall and the statement of purpose of this board was finally developed at a meeting of these representatives on December 6, 1934. It was approved by the Council on December 7.

The Advisory Board on Standards and Codes is established for two years, under the direction of the Council, with the following organization and functions. This Board is to consist of five members, a chairman appointed by the President from the membership of the Council and one member named by each of the following four committees, Boiler Code, Standardization, Power Test Codes, and Safety. This Board shall be advisory to the Council and shall assist in (1) establishing general policies pertaining to standards and codes, (2) initiating and developing standards and codes, and (3) coordinating the activities of the several committees which are represented in its membership. It plans also to cooperate with the Board of Technology.

The first meeting of the Board was held on May 9, 1935, at which the time was spent principally in discussing general policies and the methods of work of the constituent groups. It considered also the request of the Committee on Policies and Budget to the effect that the Advisory Board on Standards and Codes cooperate with it in determining the broad purposes and long-range policies which should control the Society's standards and codes activities.

Respectfully submitted,

A. D. Bailey, *Chairman*
L. A. Cornelius (Standardization) — W. M. Graff (Safety)
V. M. Frost (Boiler Code) — Francis Hodgkinson (Power Test Codes)

## BOARD OF REVIEW

The Board of Review held nine meetings during 1935 to consider the requests of members for dues cancelation and inactive status, provided in the policy which was adopted by the Council on December 2, 1934.

The number of requests received for consideration total 378, and in response, recommendations were made to the Executive Committee of Council, as follows:

| | |
|---|---|
| Approved (in part or in full) | 345 |
| Denied | 30 |
| Tabled | 3 |
| | 378 |

Dues canceled in connection with the 345 requests approved and the fiscal years to which such dues applied are given below. The cancelation of this amount in reality does not represent a real financial loss in Society revenues since the Board in each instance received satisfactory evidence of the impossibility of collecting such arrears. Furthermore, in some cases, the cancelation of part-dues arrears was made contingent on and resulted in the immediate payment of the dues-arrears balance or dues for the current year.

| Fiscal year dues ending | Amount canceled |
|---|---|
| 1930 | $5.00 |
| 1931 | 60.00 |
| 1932 | 350.00 |
| 1933 | 1,597.07 |
| 1934 | 4,782.58 |
| 1935 | 4,418.33 |
| | $11,212.98 |

In considering each request to cancel dues, the Board carefully weighed the all-important matter of loss of income to the Society. In several instances the unsolicited pledge of the member was voluntarily given that, if temporarily relieved of previous dues incurred and for which no publications or other services were rendered by the Society, he would immediately assume current dues obligations or those payable after October 1, 1935. In recommending favorable action in such cases, the continued interest of the member in the Society's welfare was retained with a reasonable certainty that active status with regular dues payments would follow in the near future. Further, the grateful acknowledgments received after notification was sent of favorable action leads the Board to believe that the Society will continue to hold indefinitely the good will of those members who have suffered serious misfortunes during the past few years. Where circumstances deemed it advisable, the Board canceled only that part of the dues arrears that would permit retaining the delinquent member on the Society roster. In such cases the member was asked to endeavor to pay the balance of arrears and current dues.

With each request for dues cancelation a detailed confidential statement was submitted by the member and individual attention given by the Board to the facts presented in such application. Where complete information was omitted, a communication was dispatched to the member and a further opportunity given to submit additional details. The recommendations of Local Sections received in certain instances were most helpful in assisting the Board.

In acting for the Council, the Board was most sympathetic in its treatment of cases where there had been a long period of faithful membership. On the other hand, the employment difficulties of the

recently graduated Junior members received equally sympathetic consideration.

In the majority of cases where dues cancelation were recommended to Council, two or more of the following conditions existed:

(a) Continued period of unemployment
(b) At present temporarily employed in relief projects
(c) At present unemployed
(d) Drastic salary readjustment
(e) Loss of income, due to bank failures, bankruptcies, etc.
(f) Loss in income due to ill health or old age.

The Board is firmly convinced of the necessity of handling promptly the membership status of dues-delinquent members and of the return to the enforcement of the Society's By-Laws canceling membership after a lapse of 15 months in membership dues. Continuation of such a policy in the future insures elimination of the suspension and dropping of several thousand delinquent members at one time as resulted in September, 1934, following a most liberal dues policy.

In conclusion, the Board offers the following recommendations for further consideration by Council:

1 That the Council continue to enforce the provisions of Par. 4, Article B5, Fees and Dues, with a liberal policy toward those members anxious to retain their membership but unable to pay annual dues for the reasons enumerated above.

2 That the provision for inactive status without membership privileges be extended one year from October 1, 1935.

3 That no member of the Board of Review serve longer than a three-year term.

Respectfully submitted,

Henry B. Oatley, *Chairman*
A. D. Blake
John P. Neff

## BOILER CODE

The Boiler Code Committee submits the following report for the fiscal year ending September 30, 1935, covering activities other than its regular routine work.

During this period the Committee held nine regular meetings and several executive committee meetings which were devoted to interpretations of the various sections of the Code and to the formulation of revisions and addenda thereto.

To keep abreast of the progress being made in the development of pressure vessels and of the materials of which they are constructed, the Committee has made necessary revisions and additions to the various sections of its Code. These changes are to a great extent the result of suggestions from manufacturers, inspectors, users, and others. These revisions were formally adopted by the Council on July 23, 1935, and distributed in pink-colored addenda sheets.

The Committee has under consideration the adoption of more comprehensive rules for the use of cast iron in the construction of cast-iron unfired pressure vessels under limited conditions. It has been brought out that there appears to be a continued demand for permission to use cast iron in Code vessels. It also appears that there are a great many unfired pressure vessels in use with some portion made of iron castings and, therefore, it appears desirable that some recognition be given in the Code to the use of cast iron which will enable manufacturers to take advantage of the extensive use of this material.

Various non-ferrous alloys as well as ferrous alloys are being developed which appear to have considerable merit for use in the construction of special pressure vessels for varying types of service. As a result, a special committee is investigating these materials with the expectation of introducing suitable provisions for Code specifications and working stresses for such materials.

Consideration was given to a request for provisions in the Code for acceptance of malleable iron for pressure parts of pipes, fittings, valves, and their bonnets. A similar provision has appeared in the Code for some time for the use of cast iron and the feeling was expressed that malleable iron should also be provided for. As a result a rule has been incorporated in the Code to allow for the use of high-grade malleable iron, which complies with the material specifications in the Code for malleable iron, for boiler and superheater connections under pressure.

Three A.S.T.M. specifications for condenser tubes and ferrule stock for unfired pressure vessels have been added by the Committee for incorporation in the Material Specifications Section of the Code. These specifications are as follows: Specifications S-29 for Seamless 70-30 Brass Condenser Tubes and Ferrule Stock (A.S.T.M. Designation B55-33); Specifications S-30 for Seamless Muntz Metal Condenser Tubes and Ferrule Stock (A.S.T.M. Designation B56-33); Specifications S-31 for Seamless Admiralty Condenser Tubes and Ferrule Stock (A.S.T.M. Designation B44-33).

Since the adoption in 1934 of a new set of rules for flat heads, the desirability of providing for additional types of flat heads was reported on by the Subcommittee on Special Design. As a result, additional rules have been added to cover the designs of crimped flat heads, of screwed-in flat heads, and of flat heads with mechanical locks.

Further study has been given to the Rules for Bolted Flanged Connections which required qualification of some of its requirements. As a result, revisions have been made of some of its requirements to eliminate the inconsistencies.

Consideration has been given to a proposal for coordination of the A.S.M.E. and the A.P.I.-A.S.M.E. Codes for Unfired Pressure Vessels. As a result, a special committee has been appointed to revise Section VIII of the A.S.M.E. Boiler Code which will embody the best features of the A.S.M.E. and the A.P.I.-A.S.M.E. Codes for Unfired Pressure Vessels.

As a result of data submitted to substantiate the reliability and safety of the flame-cutting method of preparing the edges of plate for pressure vessels to be welded under the requirements of the Code, the Code has been revised to permit the use of this method.

New rules have been adopted and incorporated in the Unfired Pressure Vessel Code to cover the use of electric-resistance butt welding for unfired pressure vessels. The requirements are similar to those in the Power Boiler Code.

After considerable experimentation and work, the Special Committee on X-Ray Requirements has selected a master set of radiographs, reproductions of which are now available.

The Committee has cooperated with the U. S. Naval Experiment Station in submitting comments on its specifications for boiler-water gages, including glasses, frames, fittings, illuminators, etc.

New rules for the construction of marine boilers and pressure vessels adopted by the U. S. Bureau of Navigation and Steamboat Inspection and based upon a report of the Special Committee to Coordinate the Marine Boiler Rules were finally adopted and issued. The part taken by the A.S.M.E. in preparing these rules was outlined in a statement published in the September, 1935, issue of *Mechanical Engineering*.

The Committee appointed V. M. Frost as its representative on the Advisory Board on Standards and Codes which was formed by the Council to establish general policies pertaining to standards and codes.

C. A. Adams, A. J. Ely, and Walter Samans were appointed members of the Main Committee of the Boiler Code Committee. John A. Darts was appointed a member of the Subcommittee on Heating Boilers. C. E. Bronson was appointed to replace M. F. Moore as a member of the Subcommittee on Heating Boilers. E. O. Waters was appointed a member of the Subcommittee on Special Design. Commander W. P. Portz replaced Commander R. F. Frellsen as the representative of the Bureau of Engineering of the U. S. Navy Department.

The Committee reports with regret the death of C. D. Thomas, chief boiler inspector of the State of Oregon and a member of the Conference Committee to the Boiler Code Committee.

The States of Maine and North Carolina have adopted the A.S.M.E. Boiler Code as their standard for the construction of power boilers, which makes a total of 21 states in which the Code is operative.

Respectfully submitted,

The Boiler Code Committee

F. R. Low, *Chairman*
D. S. Jacobus, *Vice-Chairman*
C. W. Obert, *Honorary Secretary*
C. A. Adams
H. E. Aldrich
W. H. Boehm
R. E. Cecil
F. S. Clark
W. F. Durand
A. J. Ely
E. R. Fish
V. M. Frost
C. E. Gorton
A. M. Greene, Jr.
F. B. Howell
J. O. Leech
M. F. Moore
I. E. Moultrop
C. O. Myers
H. B. Oatley
James Partington
Walter Samans
C. L. Warwick
A. C. Weigel
H. LeRoy Whitney

## BOND ISSUE

During the current fiscal year, the Bond Issue Committee has received subscriptions for $8200 for the purchase of Certificates of

Indebtedness, bringing the total up to $44,650, of which $600 in certificates are held in the treasury of the Society, being gifts of the purchasers.

Collateral of the face value of $68,750 is being held by the Trustees of the Certificates of Indebtedness. The interest due on the outstanding certificates of indebtedness was paid in full on January 1 and July 1, 1935, and for the coming fiscal year there is provision in the budget for the payment of interest when due and for the retirement of 10 per cent of the face value of the certificates outstanding.

It is expected that further activity of this Committee will not be required and it therefore requests its discharge.

Respectfully submitted,

Dexter S. Kimball, *Chairman*
Paul Doty
W. A. Hanley
C. F. Hirshfeld
John H. Lawrence
W. R. Webster
W. H. Winterrowd
Erik Oberg, *Ex-Officio*

## CAPITAL-GOODS INDUSTRIES

The situation in the captial-goods industries in the United States has been so confused and uncertain during the current year, largely because of the impact of economic forces without the industries, that the committee has found little that it could do effectively.

One research project was carried to completion, however. The January, 1935, issue of *Mechanical Engineering* published a paper on "Code Restrictions on Machinery and Production," by W. E. Hopkins and J. F. Nelson. It is a privilege to express appreciation of the diligent work of these two Junior Members of The American Society of Mechanical Engineers, and through them to acknowledge the cooperation of the Junior group in Society affairs.

Respectfully submitted,

L. P. Alford, *Chairman*
R. E. Flanders
L. W. W. Morrow
Erik Oberg

## CITIZENSHIP MANUAL

The committee during the course of the year has printed and distributed approximately sixty-five hundred copies of a pamphlet entitled "The Engineer's Duty as a Citizen," by Roy V. Wright. This pamphlet was the revision of one used in a discussion course given by Dr. Wright at the Newark College of Engineering. A copy of the pamphlet was mailed to every Student and Junior Member of the Society, and in the letter of transmittal the committee directed attention to the fact that:

"It is the object of this pamphlet to stimulate, help, and direct young men toward a larger participation in community activities, both political and otherwise; and if there is any matter which you think should be added or modified or deleted, the committee would value your suggestions very highly. Particularly in the matter of suggested questions, we are anxious to secure the reaction of the younger members of the Society.

"We are asking for this contribution on your part because we know that the success of this movement depends upon the younger men, and it is absolutely necessary that we have your suggestions and criticisms if this material is to be really helpful."

The committee received a very considerable number of criticisms and suggestions widely scattered over the United States. Most of the criticisms were from student members and came from suggestions arising from discussion in the student branches of the Society. The criticisms in the main were constructive and pointed out the need of some group discussion in connection with the distribution of the pamphlet.

The great need for something of this kind and the particular necessity for focusing the attention of the younger man on this phase of the fuller life of an engineer was generally accepted, and it was felt that the pamphlet, supplemented by some discussion conducted by a local engineer of prominence, would be particularly fruitful.

Dr. Wright has during the past few months made a further revision, and this is now ready for mailing. The committee contemplates the distribution of this pamphlet to the student branch advisers in the various colleges in the United States with the particular hope that it will furnish the basis for discussion on the part of the student members of the Society.

Respectfully submitted,

Allan R. Cullimore, *Chairman*
Roy V. Wright
W. H. Winterrowd
Lillian M. Gilbreth
Jos. W. Roe

## COOPERATIVE RELATIONS

This Committee was asked to study the problem of the relations of the Society to the various bodies in engineering and the relations between the functions of the joint bodies. Its report was presented to the Council in June, 1935, and the recommendations are under consideration by the Council.

Respectfully submitted,

Harold V. Coes, *Chairman*
Robert I. Rees
D. Robert Yarnall

## THE ECONOMIC STATUS OF THE ENGINEER

The general economic status of the engineering profession has improved somewhat during the past year. The improvement in the manufacturing industries has been reflected in the slight improvement in engineering employment. Durable-goods industries are still operating at only partial capacity, and although statistics available show that losses were incurred in these industries during the past year the earnings of the group as a whole have increased.

In cooperation with the American Engineering Council the United States Department of Labor conducted a questionnaire study of the earnings of engineers. About seventy thousand responses were received by the Department. These are being tabulated and it is expected that a report will be available shortly after the first of October. This Committee is holding itself in readiness to interpret the findings of the study in so far as they affect mechanical engineers and present them for publication and discussion if such discussion will prove helpful.

Respectfully submitted,

C. F. Hirshfeld, *Chairman*
D. S. Kimball
N. B. Oatley
H. L. Whittemore
W. E. Wickenden
C. N. Lauer
W. L. Dudley, *Ex-Officio*
W. L. Abbott, *Ex-Officio*

## ENGINEERING HISTORY

At the 1934 Annual Meeting of The American Society of Mechanical Engineers a session on Engineering History was held, at which a resolution was adopted asking the A.S.M.E. to take the lead in organizing a joint movement for the study of Engineering History.

A committee has been organized with representatives on it from the A.S.C.E., A.I.M.E., and the A.I.Ch.E.

Progress is being made.

Respectfully submitted,

Geo. A. Orrok
Jos. W. Roe

## JUNIOR PARTICIPATION

The Committee on Junior Participation approved the following methods for stimulating interest among the 3500 junior members of the Society in mechanical engineering as a profession and in the work of the Society:

1 All Local Sections should arrange dinner meetings at which at least two members should be assigned to each Junior Member with the idea of bringing the Juniors in contact with the older members of the profession in their own localities, and with the hope that personal friendships would thereby be stimulated.

2 Meetings should be arranged at which the program would be entirely in the hands of the Juniors, or, if this is not possible, that Juniors should be urged to present papers at Section Meetings.

3 Juniors should be encouraged to take part in the discussion of papers at Section Meetings, by appointment, and by sending them advance copies of the papers if possible.

4 Juniors should be urged to prepare articles for publication in *Mechanical Engineering*, and the Publications Committee should be asked to give special consideration to these papers.

5 Members of the Society should be designated as special advisers to Junior Members in their Sections.

6 The Committee should offer its assistance to General Rees of the E.C.P.D. in carrying out his program for recent graduate engineers with reference particularly to developing the characteristics which the proposed examination for certification demand.

7 In every Local Section one or more of the older and more promi-

nent members should be requested to bring about the proper mental attitude of the members in their locality with reference to the younger entrants to our profession. Invitations to Juniors to the homes of the older members should be the more general custom.

8 The Secretary of the A.S.M.E. should send every year a list of Junior Members in each Local Section to the chairman or secretary of that Section. Upon the receipt of this list the chairman should send a communication to each Junior Member inviting him to visit him personally and to attend the meetings of the Section. In the case of large Sections the chairman may wish to divide the Junior list among a number of prominent members who will be willing to correspond and to show special courtesies to a small group of Juniors.

This program is being carried out in cooperation with the Committee on Local Sections.

Respectfully submitted,

D. B. Prentice, *Chairman* — A. A. Potter
W. A. Hanley — W. H. Winterrowd

## MANUAL OF PRACTICE

The procedure adopted by the Committee looking to the ultimate preparation of a manual for the Society has been that of citing specific instances or classes of problems with which the manual should be concerned. At the Council Meeting of December, 1934, there was presented a statement concerning the engineering duties and practices to be expected of the engineer and the manufacturer, respectively. This statement was approved by Council and published in *Mechanical Engineering* for February, 1935. Subsequent to the appearance of this statement the Committee has had numerous interviews with consulting engineers and manufacturers in various commercial fields. There has been a unanimity of approval in all cases for the principles contained in the statement.

Since the promulgation of the Committee's first statement several other specific matters have been brought to our attention but it is unfortunate that because of their limited scope no action is considered advisable at this time.

On the other hand the Committee feels that the general membership of the Society should be kept constantly aware of our problems, particularly through the issues of *Mechanical Engineering*, and the Committee again urges that a definite program be initiated to ask the Society membership for cases, items, and matters which might be the subject of Committee discussion and action.

The Committee regrets the retirement of W. A. Shoudy as his leadership was of inestimable worth.

Respectfully submitted,

B. F. Wood, *Chairman* — C. G. Spencer, *Ex-Officio*
Alfred Iddles — Theodore Baumeister, Jr., *Acting Secretary*
Wynn Meredith — Philip Werner, *Junior Adviser*
J. M. Todd

## POLICIES AND BUDGET

The first phase of this Committee's work, completed in 1933, was a study of Society operation and finances used as a basis for a reduced budget for 1933–1934. The second phase of its work, which is still under way, was initiated with a new statement of Society purposes, approved for inclusion in the By-Laws by Council in December, 1934, the suggestion of changes in membership grades which are to be voted by the membership at the end of the fiscal year, and certain modifications in Society organization to simplify it and make it more responsive to the needs of the membership.

Respectfully submitted,

Harry R. Westcott, *Chairman* — John H. Lawrence
L. P. Alford — R. G. Macy
B. M. Brigman — A. L. Maillard
H. M. Burke — M. C. Maxwell
W. H. Carrier — Erik Oberg (*Ex-Officio*)
Alfred Iddles — J. W. Parker
A. C. Jewett — L. K. Sillcox
J. N. Landis — W. H. Winterrowd

## PUBLIC AFFAIRS

The Committee on Public Affairs was authorized by Council in July, 1934, to recommend to the Society policies in regard to participation in national, state, and local affairs in accord with a modification of the By-Laws made in December, 1934, which included the following statement:

"Increasing the usefulness of the organized engineering profession by ...... (*C*) encouraging engineers to participate in public affairs."

To insure complete cooperation with American Engineering Council, this Committee was constituted of present and past representatives of this Society on the Council.

This Committee has held one meeting at which a number of procedures for carrying out the purposes of the Committee were canvassed. Further activity depends in some measure on the program of American Engineering Council.

Respectfully submitted,

Roy V. Wright, *Chairman*
L. P. Alford — A. A. Potter
Paul Doty — J. W. Roe
R. E. Flanders — D. Robert Yarnall

## CALVIN W. RICE MEMORIAL

The Committee on Calvin W. Rice Memorial was appointed in October, 1934, to consider suggestions for a suitable memorial to Dr. Calvin W. Rice.

As guides for the purposes of suitable memorials, the Committee has selected Dr. Rice's keen interests in international friendliness, in young men, and in the portion of the membership not able to attend the great annual gatherings of the Society in New York.

The Calvin W. Rice Memorial Lecture has been established. This lecture is to be given at the Semi-Annual Meeting of the Society by a distinguished foreign engineer or other person with international interest. In the record book of the lectureship are the names of Dr. John H. Finley of New York, who delivered the tribute to Doctor Rice at the 1934 Annual Meeting, and of Dr. Adolph Meyer of Switzerland, lecturer at Cincinnati in June, 1935.

Further plans are under consideration.

Respectfully submitted,

H. N. Davis, *Chairman* — J. D. Cunningham
W. F. Durand — R. L. Sackett
C. E. Fuller — C. N. Lauer
J. W. Parker — E. W. O'Brien

## GEORGE WESTINGHOUSE BUST

This committee is charged with the responsibility of advising the Council as to the custody of a Bust of George Westinghouse, Honorary Member and Past-President of the A.S.M.E.

At a meeting of the Committee, December 5, 1934, Ambrose Swasey was elected honorary chairman of the committee, Dean Dexter S. Kimball chairman, L. B. Stillwell, vice-chairman, and C. E. Davies, secretary. On nomination of the Committee Messrs. L. A. Osborne and Karl T. Compton were added to its personnel.

Respectfully submitted,

D. S. Kimball, *Chairman* — K. T. Compton
Ambrose Swasey, *Honorary Chairman* — S. W. Dudley
L. B. Stillwell, *Vice-Chairman* — C. N. Lauer
C. E. Davies, *Secretary* — L. A. Osborne
W. W. Atterbury — C. F. Scott

# Joint Activities

Reports for the year 1933–1934 were also presented to the Council by representatives of the Society on a number of joint activities. Reference to some of these will be found in the Report of the Council and others are presented or summarized in the following pages.

## AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

### Section M

During the period between October 1, 1934, and September 30, 1935, one meeting of Section M, Engineering, of the American Association for the Advancement of Science was held in connection with the winter meeting of the Association, in Pittsburgh, December 27,

1934, to January 2, 1935. The principal feature of the meeting was the address of the retiring vice-president, Dr. C. F. Kettering on "Some Future Problems of Science and Engineering." The program included also problems of stress distribution and plastic deformation in metals and joint sessions on Cost and Cost Theory and History of Interesting Technological Developments, with the Section on Social and Economic Sciences and the Section on Historical and Philological Sciences, respectively.

No session of Section M was held during the summer meeting of the A.A.A.S. in Minneapolis in June, 1935.

The coming winter meeting of Section M will be held at St. Louis and active steps are under way to develop a strong engineering program.

Respectfully submitted,

SUMNER B. ELY
JOHN R. DUPRIEST } *A.S.M.E. Representatives*

## AMERICAN BUREAU OF WELDING

The relations between the A.S.M.E. Boiler Code Committee and the American Bureau of Welding continue to be on the most cordial basis and all items of welding which are referred jointly to the American Welding Society Committee and our Subcommittee on Welding are given most careful attention.

Cooperation of the American Welding Society is perfect, and our relations most satisfactory.

Respectfully submitted,

JAMES PARTINGTON, *A.S.M.E. Representative*

## AMERICAN ENGINEERING COUNCIL

The membership of The American Society of Mechanical Engineers participates in national public affairs of engineering significance through the American Engineering Council, with offices in Washington, D. C. In keeping with its long-established policy of seeking to serve the common interests of all engineers as well as those of its own members, the A.S.M.E. has actively supported the work of the A.E.C. from the beginning.

The membership of American Society of Mechanical Engineers is officially represented in these common activities of the American Engineering Council through five delegates. Both nationally and locally, many other members participate in the work. Their delegates, on the occasion of the annual meeting of the Council, held in January, in Washington, and through the year, through their service on committees of the Council and through coordination between the staff of the A.S.M.E. and the staff of the Council forward many matters of common interest to all engineers and especially to the members of our society.

With the great increase in the legislative and administrative activities of the Federal Government as they have affected industry and engineering during the past three years, there has been ample opportunity for mechanical engineers to relate themselves to this work. Contacts in Washington, long established, understanding of the procedures of the Federal Government, and the development of staff and committees to relate the American Engineering Council to these rapidly growing government activities have enabled the profession to participate intimately through what has come to be called the Washington Embassy of American engineers and engineering.

This rapid development of Government agencies relating in one way or another to the development of our natural resources, our public utilities, our capital goods, including machinery and construction, and our transportation and communication industries, has made the task of the American Engineering Council very much greater than ever before.

The following of legislation, the interpretation of Executive Orders, and the aiding in the staffing of government bureaus and consultations on policies and methods of fulfilling much of the new legislation has related American Engineering Council in new ways to our national program. It is literally true that more legislation has been passed directly affecting the welfare of engineers during the last two years than through the ten years preceding. To the original purpose of the founders of the American Engineering Council to provide an organization to aid in molding legislation on engineering matters of public interest has been added the past year or two the practical task of molding methods in the application of legislation.

The first organized approach to the study of the present widely expanded government program with regard to furnishing a means of interpreting to the profession as a whole the details of the many legislative programs took place at the annual meeting of the Council in January, 1935. In line with the need, instead of devoting the entire time to business sessions, a symposium of Federal activities was held and a first hand account was given by members of the Federal Government announcing their plans and deeper purposes as related to:

(1) Planning and the development of natural resources
(2) Construction
(3) Durable-goods industries.

Among the prominent Federal officials who addressed the several sessions were: Hon. Marriner S. Eccles, Governor, Federal Reserve Board; Hon. M. L. Wilson, Assistant Secretary of Agriculture; Dr. Harlow S. Person, of the National Resources Board; Capt. R. S. Patton, director, U. S. Coast and Geodetic Survey; Dr. Isador Lubin, commissioner of labor statistics; Col. D. H. Sawyer, director, Federal employment stabilization office; Clarence McDonough, chief of the engineering division, Public Works Administration; Charles C. Anthony, industrial adviser, and Thomas Hibben, chief engineer, Federal Housing Administration; Wm. P. Witherow, vice-chairman, industrial advisory board, National Recovery Administration; and R. E. W. Harrison, chief, machinery division, U. S. Bureau of Foreign and Domestic Commerce.

Dr. Harold G. Moulton, president, The Brookings Institution, addressed the largest group ever assembled to attend the Annual Dinner. He discussed the economic trends leading to the depression.

The opportunity to hear these Government officials was afforded not only to members of the assembly and to engineers resident in Washington and environs, but also to secretaries of engineering societies who had assembled from all parts of the United States to discuss their own problems at a conference held under the auspices of American Engineering Council and in conjunction with its annual meeting.

In line with this aggressive policy of coordination, the annual assembly voted to provide a method for further correlation of activities of engineers in public affairs through a plan for local membership whereby local organizations as well as national organizations could participate in the work of Council without duplicating financial structures. To this end a committee, consisting of Messrs. Bickelhaupt, Alford, Trullinger, and Wendt, with Dr. McClellan as adviser, proposed a plan of membership to open the way to affiliation with the Council to a large number of state and local engineering organizations. This new plan permitted such an organization to become a member for the nominal fee of $25 per thousand members per year, the expenses of the delegate at the annual meeting to be paid by the member-organization.

Under this plan the following engineering organizations have joined Council since the first of the year:

Arkansas Engineers Club
Cleveland Engineering Society
Engineers Club of Baltimore
Engineers Club of Columbus
Engineers Club of Philadelphia
Engineers Club of St. Louis
Engineering Societies of New England
Engineering Society of Western Pennsylvania
Florida Engineering Society
Louisiana Engineering Society
Michigan Engineering Society
Providence Engineering Society
South Carolina Society of Engineers

A third policy established during the year was to strengthen and further cooperation between member-organizations and the Council through the dissemination of information as widely as possible. With the cooperation of the editors of the journals of the Founder Societies and of the editors of the other technical journals, regular monthly reports of Council's activities are published for the information of the members.

Beginning July 1, 1935, the information service has been further strengthened by the establishment of a plan of placing on file in the offices of member-organizations the basic laws of the administrative and executive orders dealing with engineering matters. This additional "Washington Embassy Service" has been developed from the viewpoint of increasing not only the general knowledge of members of the societies but of making available locally information concerning government expenditures which would constitute the basis for employment of many individuals.

A mimeographed monthly news letter is mailed to delegates, committee members, and officers of local sections, for their personal information.

The fourth policy in course of development is the establishment in each state of public-affairs committees. In accordance with a plan approved at the annual meeting in January, these committees are

to be coordinated with the national Committee on Public Affairs. This plan of coordination of state committees on public affairs rests for its success upon the cooperation of local sections and of local engineering societies and can only come about gradually through the active participation of local organizations in districts not now represented in national affairs. The general purpose of this program is to take advantage of present organizations to provide the machinery for securing the organized discussion of public problems by engineers instead of setting up any new organization or duplicating the activities of others.

In the fifth place, to provide coordination within the committee activities of American Engineering Council itself. The Executive Committee of Council approved the development of three broad classes of committees:

(1) Public-affairs committees
(2) Engineering and economic research and inquiry committees
(3) American Engineering Council operating committees.

In order to simplify procedure, in so far as possible, special committees have been made subcommittees of standing committees.

In the first group is included the Committee on Public affairs and related to it as subcommittees are the committees on administration of public works, aeronautics, competition of Government with engineers in private practice, engineers water power policy, flood control, patents, rural electrification, and water resources, also representation on the Advisory Council of the Federal Board of Surveys and Maps.

In the second group are included the committee on engineering and allied technical professions, the relation of consumption, production and distribution, and the naval towing tank; also representation on the board of directors of the National Bureau of Economic Research and the Board of National Councilors of Purdue Research Foundation.

In the third group, are included the committee on constitution and by-laws, to which the committee of tellers serves as a subcommittee, the finance committee, committee on membership and representation, publicity and publications, and regional activities.

The activities of four committees of the Council will have special interest for members of The American Society of Mechanical Engineers.

(1) The Committee on Aeronautics, under the chairmanship of Grover C. Loening, is proceeding actively in carrying out the program by Council. The major features of the program are:

(a) That a sum of \$50,000 be appropriated each year as an addition to the budget of the National Advisory Committee for Aeronautics and subsequently earmarked for research work to be done by universities and other institutions of public learning.

(b) That none of such appropriation should be employed for educational purposes, construction of buildings or basic equipment.

(c) That a committee be appointed entitled "Committee on Cooperation between the N.A.C.A. and Universities Interested in Aeronautical Engineering;" further that this committee should contain representatives of the National Advisory Committee for Aeronautics, of the Army, of the Navy, of the Department of Commerce, of the industry selected by the Aeronautical Chamber of Commerce, and of the universities engaged in aeronautical work.

(d) That scientific workers at the universities or technical institutes desiring to conduct research would submit to the N.A.C.A. a formal plan for such research, stating the object of the investigation, and the personnel available for execution for a given piece of research. The allotment of funds would be entirely within the discretion of these committees.

(e) Publications of worth-while research would be in the form of N.A.C.A. technical reports or technical notes.

Dr. Alexander Klemin, secretary of the committee, has made several contacts in Washington in the interest of forwarding the program.

(2) Committee on Engineering and Allied Technical Professions.

The work of this committee is described in a later part of this statement.

(3) The Committee on Patents, under the chairmanship of Dean A. A. Potter, is studying ten bills relating to patents and to copyright laws which are pending before the Patents Committee of the House of Representatives. The legislation deals with such subjects as provision of counsel for the defense and prosecution of rights of indigent patentees, recording of patent-pooling agreements and contracts with the Commissioner of Patents, permitting single signature in patent applications and validating joint patent for sole invention; limiting the life of a patent to a term commencing with the date of application, compensation of owner for infringement of patents by U. S. Government, prevention of fraud, deception, and other improper practice in connection with business before the U. S. Patent Office, providing protection for registration of designs for textiles and other materials, making effective in the United States provisions of the International Convention for the Protection of Industrial Property relating to time limitations in which a foreigner may make application for a design patent, or a trade-mark application.

A.S.M.E. members of the committee are Dean A. A. Potter, chairman, W. C. Lindemann, Edwin J. Prindle, and E. N. Trump.

(4) The Committee on Water Resources, under the chairmanship of Wm. S. Conant, a former representative of the A.S.M.E. on the assembly of the Council, has submitted a report which the Council approved. The report points out that two fundamental needs for a National Water Resources Policy are: (1) complete and correlated data; (2) comprehensive study of water-control legislation. A federal Bureau of Water Resources is endorsed in principle and an interdepartmental Board of Water Resources Investigations is recommended to correlate investigational functions of federal units. Extension of the work of the Water Planning Committee is recommended through a National Advisory Water Planning Agency for comprehensive, integrated drainage-basin planning.

The annual report of the Council will include an analysis of the work of all the committees.

### Procedure as to Legislation

With so much of engineering interest at stake in the session of Congress just passed, it seems timely to summarize the policies and methods followed by the Council in legislative matters. The staff has had for its guidance:

(1) Policies adopted by the Assembly and Administrative Board at Annual Meetings.

(2) Advice on new matters from special and standing committees.

(3) Precedent of several years on matters which do not require new rulings.

(4) The viewpoint of public interest as a fundamental reason for participating in legislative activities.

(5) The corollary viewpoint of advancing the economic status of the profession.

The factors of public interest and the status of the profession are closely related in problems constantly arising in connection with the Federal program, due to the extraordinary relation of government to business at present. *Competent engineers must be employed where engineers belong if the public interest is to be protected* against faulty planning and wasteful execution.

Although the "Washington Embassy" of engineers may not jump into drastically new lines of action in the name of the profession without due consultation and approval, it is not hemmed in by ponderous procedure. The precedent set on past work, recognized as in the interest of the profession, gives sufficient latitude for quick action on immediate, practical steps and leaves only the long-range phases for more deliberate action.

Legislation which Council follows for engineers includes the following general categories:

(1) *Construction:* Federal appropriations and administrative machinery for construction. (The work-relief bill.)

(2) *Development of Industries:* Amendments to the National Industrial Recovery Act, new patent legislation, etc.

(3) *Development of Natural Resources:* Bills relating to water power, navigation, reclamation, soil-erosion control, surveys and maps, and similar public activities wherein the engineer serves in the development of "our national plant."

(4) *Engineers' Welfare:* General legislation in the field of unemployment insurance, old-age pensions, etc; bills such as civil-service measures, engineers' compensation on federal and relief work, etc., more directly affecting the engineer.

Scores of bills under each of the above headings have been under consideration. With its limited staff the Council has found itself obliged to concentrate on those of the greatest importance to the profession. Where needed, information and arguments have been presented to Congressional Committees in open hearings or otherwise. The Public Affairs Committee and its subcommittees are sent copies of important bills and documents and kept generally informed.

### Cooperation With Government and Placement of Engineers

As indicated above, so active have been the developments of Government agencies that what might be called a by-product in normal Council activities has become very important.

From time to time the Council has been called upon to recommend engineers for positions and works in cooperation with the Engineering Societies Employment Service in which the A.S.M.E. participates. At the request of the Government, names of engineers technically qualified for positions, have been submitted to various agencies. Some 74 Government divisions now employ engineers.

In addition to working from day to day on placement problems, the Council has made a number of analyses of the number and distribution of engineers. These analyses led to a further activity, namely, the census of engineers which is being made with the cooperation of the national, state, and local societies. Under the direction of a standing committee of Council on engineering and allied technical professions the Bureau of Labor Statistics of the U. S. Department of Labor

conducted a special census of engineers with particular reference to educational background, occupation, income, and present status of employment. The results of the questionnaire will be presented in a report by the Bureau of Labor Statistics and it is expected to have a far-reaching influence on policies concerning engineering education and percentage distribution of engineers both by profession and by industry, the basis for professional consideration or compensation, and other policies of direct interest to the individual engineeer.

### Officers and Delegates

President J. F. Coleman, past-president of the American Society of Civil Engineers, and consulting engineer of New Orleans, La., is serving the second of his two-year term as president. C. O. Bickelhaupt, of New York, Alonzo J. Hammond of Chicago, Paul Doty of St. Paul, and W. H. Woodbury of Duluth are vice-presidents. C. E. Stephens of New York is treasurer.

Work of the Council in Washington is essentially a staff activity. The personnel of the organization is headed by Frederick M. Feiker, as executive secretary, serving his second year. During the year, with the approval of the executive committee, Lemuel V. Reese joined the organization as assistant secretary. Mr. Reese, joining the staff from the F.E.R.A. organization, brought a first-hand knowledge of the present government personnel, as well as a background of experience in engineering and industry. The secretaries of Council and of the national member organizations meet each month to assure coordination of effort.

The last three years have seen a constantly increasing opportunity for the engineering profession to contribute its viewpoint and constructive suggestion in public affairs. The delegates of The American Society of Mechanical Engineers believe it fortunate that there has been available in Washington an organization and headquarters for service, the American Engineering Council. The organization has been pointed to by societies of the other professions as an example to be followed.

The American Society of Mechanical Engineers, from the beginning has supported this coordinated center for common action and its representatives believe it has possibilities of even wider and greater usefulness to the public and indirectly to the profession.

Respectfully submitted,

R. E. Flanders, *Chairman*
L. P. Alford
Paul Doty
A. A. Potter
D. Robert Yarnall
H. V. Coes } *Alternates*
J. W. Roe }

## AMERICAN STANDARDS ASSOCIATION

On April 25, 1935, the Standards Council of the American Standards Association voted to reorganize parts of the Association's structure to cope with the widening range of standards work. The chairman of the Standards Council, J. C. Irwin, was authorized to organize a mechanical committee, a textile committee, and a building-code correlating committee. Other intra-industry committees will be formed from time to time as the need develops. Because of the increased interest in standards for consumer goods, an advisory committee on ultimate consumer goods was authorized. This body will advise the Standards Council on the problems in this field.

During the year the Federal Housing Administration became a member body of the American Standards Association, and the American Automobile Association, Manufacturing Chemists Association, and the Motor Truck Association of America have become associate members. A total of 36 member bodies represents 40 national organizations. Of these nine are governmental bodies, eight are technical societies, and 19 are trade associations. The 13 associate members consist of six technical societies and seven trade associations. More than 600 national groups are now cooperating in developing and revising standards and safety codes under the procedure of the American Standards Association.

Officers of the Association are: Howard Coonley, representing the A.S.M.E., president; F. E. Moskovics, representing the Society of Automotive Engineers, vice-president; P. G. Agnew, secretary, and Cyril Ainsworth, assistant secretary. J. C. Irwin is chairman of the Standards Council and F. M. Farmer is vice-chairman.

As of September 10, 1935, the Association has approved 301 standards, 65 of which are in the mechanical field. Since October 1, 1934, 36 standards have been approved, six important projects being in the mechanical field. During the past 12 months nine requests for the initiation and approval of existing standards were received.

Respectfully submitted,

C. W. Spicer, *A.S.M.E. Representative*

## THE ENGINEERING FOUNDATION

The most important feature of The Engineering Foundation's year of activity was the celebration of the twentieth anniversary of its founding. For the celebration the regular meeting, October 18, 1934, was selected. Dr. Swasey accepted the Foundation's invitation to be the guest of honor. Invitations to a subscription dinner drew acceptance from 78 persons: past and present members of the Foundation and United Engineering Trustees, Inc., officers of the Founder Societies and cooperating organizations of engineers and scientists, and a few personal friends of the Founder. Chairman Charlesworth presided and at the close of the program presented Dr. Swasey an engrossed testimonial signed by all the persons present. Addresses were made by Harry P. Charlesworth, Frank B. Jewett, a former vice-chairman of the Foundation, Karl T. Compton, president of Massachusetts Institute of Technology, and representing Harold V. Coes, president, United Engineering Trustees, Inc., vice-president George L. Knight.

Total book value of endowments, December 31, 1934, was $882,000; and the E. H. McHenry bequest in the hands of executors until decease of two life beneficiaries, appraisal at probate of will in 1931, was approximately $400,000. These capital funds are held and administered by United Engineering Trustees, Inc. The net income from endowment was $5000 in 1915 and $40,000 in 1934. The Foundation Board has discretionary power in the use of income. For enterprises which the Foundation has aided, large contributions of money, services, and materials have often been obtained from organizations and firms in industry.

The activities in 1934 included investigations of concrete and reinforced-concrete arches, earths and foundations, and plastic properties of concrete in the civil-engineering field; critical review of the world's literature on alloy irons and alloy steels since 1890, and barodynamic research, both sponsored by the American Institute of Mining and Metallurgical Engineers; in cooperation with committees of The American Society of Mechanical Engineers, studies of effect of temperature on properties of metals, cutting of metals, thermal properties of steam, mechanical springs, riveted joints, wire rope, boiler-feedwater studies, fluid meters, and strength of gear teeth; under sponsorship of the American Institute of Electrical Engineers and electric-welding research on pure-iron electrodes.

Assistance was given also to the Engineers' Council for Professional Development, Personnel Research Federation, and for a survey by The Engineering Index.

The present officers of the Engineering Foundation are: Chairman, Harry P. Charlesworth; first vice-chairman, D. Robert Yarnall; second vice-chairman, Edwards R. Fish; members of executive committee, Otis, E. Hovey, John V. N. Dorr, and Edwards R. Fish; representative on executive board of National Research Council, Harry P. Charlesworth; director and secretary, Alfred D. Flinn.

Revised Rules of Administration have been drafted in accordance with the revised by-laws of the United Engineering Trustees, Inc. Copies of these rules are now available in pamphlet form. They govern applications for grants and the other procedures of the Foundation.

*Welding Research.* On the invitation of A.I.E.E. a conference was held on April 22 of 18 representatives of technical organizations and the industry. This conference discussed plans and possibilities for a comprehensive welding research project, and nominated eight members of a Committee to be appointed by the Foundation. This Committee was appointed on April 25 and held a meeting on May 6 attended by all members, the chairman of the conference and the director of the Foundation. This meeting stated the principal elements of a program, appointed a Subcommittee on Literature and a Subcommittee on Research Projects, and directed that a canvass be made of contributions to be expected from industrial concerns, especially of services and materials for the research.

The members of the Welding Research Committee are: Comfort A. Adams, chairman, professor of electrical engineering, Harvard Engineering School; David S. Jacobus, advisory engineer, Babcock and Wilcox Company; Henry M. Hobart, consulting engineer, General Electric Company; James H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories; Glen F. Jenks, commanding officer, Watertown Arsenal; Frederick T. Llewellyn, research engineer, U. S. Steel Corporation; John J. Crowe, engineer in charge of apparatus research and development for the Air Reduction Company; and William Spraragen, secretary, consulting engineer.

Respectfully submitted,

W. H. Fulweiler (1936) }
D. Robert Yarnall (1936) } *A.S.M.E. Representatives*
A. E. White (1939) }

## ENGINEERING SOCIETIES EMPLOYMENT SERVICE

The Engineering Societies Employment Service, a joint activity conducted by the four National Societies, maintains offices in the Engineering Societies Building in New York, at Chicago, and San Francisco. Each of these offices is in charge of a manager who is supervised by a local Advisory Board. Each Advisory Board is made up of a member of each of the Four National Societies.

In New York, the Society of Naval Architects and Marine Engineers participates; in Chicago, the Western Society of Engineers; and in San Francisco, the Engineers' Club and the California Section of The American Chemical Society.

It has been found necessary during the last few years to restrict the service to members of the participating organizations, unless no member can be found who has the necessary qualifications. In New York, non-members of the Societies have been aided through a special activity, known as the Professional Engineers' Committee on Unemployment, which was organized and conducted by the New York Local Sections of the four National Societies. In Chicago and San Francisco, where there was no activity comparable to that carried on by the P.E.C.U., the Employment Service served a reasonably large number of non-members. This was in cases of openings for stationary engineers, chemical engineers and special classifications generally found within the membership of the participating societies. The fees collected through these placements reduce the expense of operation on the part of the societies to underwrite any deficit that occurs from year to year.

Tables showing the registrations and placements for each of the offices follow directly.

REGISTRATIONS, BY SOCIETIES

For New York, Chicago, and San Francisco offices from August 1, 1934, to July 31, 1935, inclusive

| | A.S.C.E. | A.I.M.E. | A.S.M.E. | A.I.E.E. | W.S.E. | S.N.A. | A.C.S. | E.C. | N.M. | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| New York | 341 | 110 | 405 | 313 | 4 | 9 | .. | .. | 74 | 1256 |
| Chicago | 56 | 32 | 83 | 88 | 62 | .. | .. | .. | 281 | 602 |
| San Francisco | 92 | 97 | 92 | 62 | .. | .. | 17 | .. | 252 | 612 |
| Total | 489 | 239 | 580 | 463 | 66 | 9 | 17 | .. | 607 | 2470 |

PLACEMENTS, BY SOCIETIES

For New York, Chicago, and San Francisco offices from August 1, 1934, to July 31, 1935, inclusive

| | A.S.C.E. | A.I.M.E. | A.S.M.E. | A.I.E.E. | W.S.E. | S.N.A. | A.C.S. | E.C. | N.M. | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| New York | 116 | 27 | 242 | 112 | 1 | 1 | .. | .. | 116 | 615 |
| Chicago | 14 | 1 | 32 | 18 | 52 | .. | .. | .. | 130 | 247 |
| San Francisco | 18 | 27 | 36 | 9 | 1 | 1 | 5 | 1 | 80 | 178 |
| Total | 148 | 55 | 310 | 139 | 54 | 2 | 5 | 1 | 326 | 1040 |

Respectfully submitted,

C. E. Davies, *A.S.M.E. Representative*

## ENGINEERS' NATIONAL RELIEF FUND

From August 15, 1934, to September 4, 1935, the Board of Direction of the Engineers' National Relief Fund considered and acted upon seven applications for loans. Of these cases two were those of the A.S.C.E., one, A.S.M.E., and four were of non-members. A total of $570 was paid out of which $345 was returned during this time.

Except in extreme and exceptionally worthy cases, the Loan Fund was available only to members of the four National Societies or to members of local societies with which the Local Sections of the four National Societies are affiliated. It was understood that the loan was to be on the basis of a revolving fund, made for the briefest possible period consistent with providing an emergency service. The basis for this policy was to have the fund circulating to the greatest extent. Assistance to engineers in dire distress was generally determined by a study of answers to a group of questions, which answers wherever possible were furnished as a result of investigation by local organizations.

Respectfully submitted,

William G. Atwood (Am.Soc.ofC.E.), *Chairman*
Landon F. Strobel (A.I.M.E.)
E. B. Meyer (A.I.E.E.)
William A. Shoudy (A.S.M.E.)[1]

[1] W. W. Macon, A.S.M.E. representative, died January 1, 1935. Mr. Shoudy was appointed to succeed him on the Board of Direction.

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

The eighth Plenary Meeting of the International Electrotechnical Commission convened on June 18, 1935, at Scheveningen, Holland, for the first week of meetings and continued during the following week in Brussels, Belgium.

There were over four hundred and fifty delegates present, of whom 14 represented the United States National Committee of the I.E.C. The American delegation was led by Dr. C. H. Sharp, President of the U.S.N.C., and the delegates were selected in the greater part from the sectional committees of the A.S.A. and the A.S.M.E. Committees on Power Test Codes. American industry, therefore, participated directly in the deliberations of the I.E.C.

Twenty advisory-committee meetings were held during the two weeks, including those on steam turbines and internal-combustion engines. The committees which held sessions at Scheveningen dealt with nomenclature, aluminum, insulating oils, rules and regulations for overhead lines, radio communication, electrical installations on ships, electric cables, electronic devices and steam turbines, while at Brussels meetings were held on symbols, lamp caps and holders, standard voltages and currents and high-voltage insulators, electric-traction equipment, measuring instruments, terminal markings, switchgear, accumulator batteries, and internal-combustion engines.

The International Electrotechnical Commission embraces practically every branch of the electrical industry and from the point of view of standardization in its broadest sense is dealing with matters of the highest commercial importance. The I.E.C. is engaged in preparing standard specifications which can serve as models for the use of the several member nations in international trade. In its 30 years of existence it has accomplished more than is generally recognized. And, although the I.E.C. recommendations are not so much in the public eye as they might be, they are constantly permeating the national standards as well as industry as a whole, where their identity or origin is often lost.

The U. S. National Committee of the I.E.C. functions as Secretariat for Advisory Committees No. 1 on Nomenclature; No. 4 on Hydraulic Turbines; No. 5 on Steam Turbines; No. 14 on Rating of Rivers; and No. 19 on Internal-Combustion Engines. During the year preparations had been made for the meetings of Advisory Committees No. 1, No. 5, and No. 19.

Advisory Committee No. 5 on Steam Turbines held a week of meetings at Scheveningen while No. 19 on Internal-Combustion Engines met for a week in Brussels. At both meetings a considerable degree of international agreement was attained, which was due, in part, to the fact that all business coming before the committees had been the subject of extended correspondence between the various national committees and the Secretariat over a period of four years. The written opinions of the various national committees were condensed into a number of printed Secretariat reports which were submitted at the meetings.

At the meetings of Advisory Committees No. 5 and No. 19, the U. S. National Committee was represented by Francis Hodgkinson, Acting Director of the Secretariat on Steam Turbines and Director of that on Internal-Combustion Engines, by K. McH. Irwin, delegate and by C. B. LePage, Assistant Director of both of the Secretariats.

Respectfully submitted,

H. N. Davis
E. C. Hutchinson
Francis Hodgkinson
*A.S.M.E. Representatives*

## ENGINEERS' COUNCIL FOR PROFESSIONAL DEVELOPMENT

The program of Engineers Council for Professional Development looking toward the enhancement of the status of the engineer is divided into four parts:

(1) Educational and vocational orientation of young men
(2) Cooperation between the engineering profession and engineering schools
(3) Further personal and professional development of young engineering graduates
(4) Establishment of suitable standards for professional recognition.

During the year substantial progress has been made in all elements of this program.

The most tangible progress has been made in the matter of cooperation between the profession and education. In this field the preliminary work on the program for accrediting curricula in engineering schools has been completed and as the year drew to a close steps were being taken to accredit some twenty institutions in the New England and Middle Atlantic areas.

In the establishment of suitable standards for professional recognition, two Societies, the American Society of Civil Engineers and our own, have initiated changes in their Constitutions to provide for modification of the requirements for the grade of Member and the addition of a grade of Fellow.

In the vocational orientation of young men, groups have been organized in over a score of centers throughout the United States to provide this guidance for prospective candidates for engineering schools.

In the post-college development work a leading list and a personal self-analysis blank have been perfected and distributed.

The complete report of the work of this important body may be secured for the sum of ten cents by writing to the Secretary at 29 West 39th Street, New York City.

Respectfully,

C. F. Hirshfeld, W. E. Wickenden, William L. Batt — *A.S.M.E. Representatives*

## JOINT AWARDS

The A.S.M.E. participates in a number of joint awards. These follow together with brief statements giving the purpose of the awards, the participating bodies, the names of the A.S.M.E. representatives for 1934–1935, and the awards made between October 1, 1934, and September 30, 1935.

*John Fritz Medal*, for notable scientific or industrial achievement; Am.Soc.C.E., A.I.M.E., A.S.M.E., A.I.E.E.; R. V. Wright, C. N. Lauer, A. A. Potter, Paul Doty. Award for 1935 to Frank Julian Sprague.

*Gantt Gold Medal*, for distinguished achievement in industrial management as a service to the community; Institute of Management Division of A.S.M.E.; Jos. W. Roe, David B. Porter, F. E. Raymond. Award for 1935 to Arthur Young.

*Daniel Guggenheim Medal*, for notable achievement in advancement of aeronautics; A.S.M.E., S.A.E., Canada, England, France, Germany, Holland, Italy, Japan; H. I. Cone, Porter H. Adams, E. E. Aldrin, B. M. Woods. Award for 1935 to William F. Durand.

*Herbert Hoover Medal*, for distinguished public service; Am.Soc. C.E., A.I.M.E., A.S.M.E., A.I.E.E.; Ambrose Swasey, C. N. Lauer. No award.

*Alfred Nobel Prize*, for most meritorious technical paper published by participating societies; Am.Soc.C.E., A.I.M.E., A.S.M.E., A.I.E.E., Western Society of Engineers; Arthur M. Greene, Jr. Award for 1935 pending.

*Washington Award*, for advancing human progress through engineering; Am.Soc.C.E., A.I.M.E., A.S.M.E., A.I.E.E., Western Society of Engineers; Geo. F. Gebhardt, C. B. Nolte. Award for 1935 to Ambrose Swasey.

## NATIONAL MANAGEMENT COUNCIL

During the past year the National Management Council has been engaged primarily in plans for American participation in the Sixth International Congress for Scientific Management, held in London, England, July, 1935. The A.S.M.E. Management Division cooperated in this effort. The Congress was reported as being highly successful with an attendance of over 2000. The American management bodies were represented by five, all members of the A.S.M.E. The next International Management Congress will be held in the United States in 1938.

The informal suggestion from the National Management Council resulted in the planning and organizing of a series of nine meetings in the Metropolitan area under the joint auspices of the Sections of societies and associations concerned with management problems.

Respectfully submitted,

J. A. Piacitelli, C. W. Lytle, H. V. Coes — *A.S.M.E. Representatives*

## NATIONAL RESEARCH COUNCIL

### DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

In the Division of Engineering and Industrial Research there are four main research projects in which steady progress is being made: highway research; electrical insulation; heat transmission; and welding research.

*Highway Research.* The Highway Research Board held the largest meeting of a series of 14 annual meetings on December 6 and 7, 1934. The registered attendance was 383 against 314 for last year and 282 for 1932. From the program of this meeting 20 papers have been selected for publication in the Proceedings of the Board which will be issued later (in an edition of 2000 copies). In addition the Board issues Highway Research Abstracts (mimeographed) ten times during the year for the presentation of information concerning important unpublished research work.

Among its active projects are:

(*a*) Investigations on the use of high-elastic-limit steel for concrete reinforcement
(*b*) The warping of concrete pavement slabs
(*c*) The stabilization of the surface of low-cost-type roads
(*d*) Studies on highway costs in relation to economic planning.

*Electrical Insulation.* The Committee on Electrical Insulation held its seventh annual meeting on October 25 and 26, 1934, at the University of Illinois with an attendance of about 90. Nineteen technical papers were presented dealing with current investigations on the theory and practice of electrical insulation. These papers have been published (in planographed form) for the committee with the assistance of the Brooklyn Edison Company.

Annual meetings of this Committee are now recognized as very useful occasions for the exchange of information in regard to current research in this country on dielectrics. In addition to publishing the papers at these meetings, the Committee has sponsored the preparation of a series of four monographs (published commercially) the last of which will be issued next spring. These monographs deal with "The Nature of a Gas," "Liquid Properties of Glass," "Liquid Dielectrics," and "Impregnated Paper Insulation."

*Heat Transmission.* The Committee on Heat Transmission has sponsored the preparation of a second treatise on heat insulation which will be prepared by E. C. Rack, of the Johns Manville Corporation, and is expected to be issued early in 1936. This new volume, together with the book on "Heat Transmission" of Prof. W. H. McAdams, of the Massachusetts Institute of Technology, issued in 1933, will provide a complete review of present knowledge of the transmission and conservation of heat.

*Welding Research.* The Committee on Fundamental Research in Welding held its fourth annual conference in New York on October 2, 1934, with an attendance of 42. The object of this Committee is to place welding engineers in touch with university physicists and metallurgists who can undertake research on fundamental problems encountered in the fusion of metals in welding, particularly iron and steel. Ten special reports were completed during the year, by collaborators with this committee and the committee is in touch altogether with some 66 research projects now in progress in university, governmental, and industrial laboratories.

*Cooperation With the Science Advisory Board.* The Division of Engineering and Industrial Research has also materially assisted the Science Advisory Board of the National Research Council throughout the year by maintaining contacts with government officials in the Department of Commerce. The Director of the Division has made frequent trips to Washington and has been closely in touch with a number of governmental agencies which are concerned with progress of industrial research.

Respectfully submitted,

David S. Jacobus, F. Malcolm Farmer, Bert Houghton — *A.S.M.E. Representatives*

## UNITED ENGINEERING TRUSTEES, INC.

The United Engineering Trustees, Inc., has three departments, The Engineering Foundation, the Engineering Societies Library, and the Administrative.

Under By-Laws revised in 1934, operations have been greatly simplified and clarified. The newly created Real Estate Committee has functioned efficiently in matters outside the technical operation of the Engineering Societies Building. It has cooperated in many ways with the Finance Committee, thereby distributing the heavy responsibilities placed upon a few men already overloaded by their

professional interests. Distinct progress has been made toward the initiation of another permanent committee for the purpose of raising funds by gift, deed, bequest, or other method, "for the furtherance of research in science and engineering or for the advancement in any other manner of the profession of engineering and the good of mankind."

The corporation continues as treasurer for the Professional Engineers' Committee on Unemployment and has recently accepted appointment as treasurer for Engineers' Council for Professional Development, thus further serving the profession and its interrelated organizations, and fulfilling the purpose of its creation by the Founder Societies.

Members of the governing bodies of the Founder Societies and officers of their joint functional organizations met on the evening of May 20 and heard progress reports of the many projects which are operated jointly by the Founder Societies. The benefit of social contact by members of these groups was felt to be an important factor in tending to knit together more firmly the entire profession, through better understanding of the work and objectives of the different groups of joint activities of the Founder Societies.

Important improvements are being made in the public-address system in the Engineering Auditorium in order that it shall represent the ultimate in service to its users. This new system, coupled with our motion-picture projectors will make possible sound and color pictures in the auditorium, and should prove attractive to Society users and patrons and bring additional engagements. Seats have been added on the main floor of the auditorium thus increasing comfort by the more judicious use of space. Windows throughout the Engineering Societies Building have been repaired to prevent drafts and discomfort to the occupants of the offices, at the same time conserving steam, and the physical property.

The several departments of United Engineering Trustees, Inc., have remained within their budgets which were made on a most conservative basis. The income from the Engineering Societies Building activities was at a minimum owing to the continued reduction on a most conservative basis.

Full statistical and detailed reports on the activities of the United Engineering Trustees, Inc., is presented to the Societies in the Annual Reports of the President and the General Manager in October of this year.

Respectfully submitted,

D. Robert Yarnall
Walter Rautenstrauch
Harold V. Coes
*A.S.M.E. Representatives*

## Service Rendered by the Office of the Society

The function of the office of the Society is to perform the regular duties connected with the many committee activities of the Society, to serve as a service bureau to the members and on behalf of the members as a service bureau to the public, in so far as facilities and resources permit. In general, the office staff keeps the books, maintains an accurate address record, edits the publications, secures the advertising, and maintains contacts with the Local Sections, Professional Divisions, Student Branches, and Technical Committees, all under the policy direction of the Council. In detail, however, the activities of the office are complicated. To aid in understanding them the following brief statement is given as an indication of the volume of work being performed in each group.

*Secretary's Department* (*3*): Secretary and two assistants.
- Supervision. Coordination. Contacts with joint bodies. Direct service to the Council, Executive Committee, and Special Committees.

*Field Department* (*12*): Assistant Secretary and eleven assistants nine in New York, one in Chicago, one in Tulsa.
- Seventy-one Local Sections (visited 38 in 1935), correspondence, speakers lists, appropriations.
- Seventeen Professional Divisions (with about 60 subcommittees), six National Meetings.
- Annual Meeting, 50 sessions, 105 authors, 60 committee meetings.
- Semi-Annual Meeting, 20 sessions, 42 authors.
- One hundred and thirteen Student Branches (visited 48 in 1935), 3300 applications for student membership; 10 district conferences.
- Admissions, 2000 applications requiring 6000 communications, 340 resignations.
- Employment, Engineer's National Relief Fund, Professional Engineers' Committee on Unemployment, Engineering Societies Employment Service.
- Special Duties, technical inquiries, foreign visitors, awards, Max Toltz Fund, Freeman Fund, handling cases of 6240 dropped or suspended members.

*Editorial Department* (*6*): Editor, five full-time assistants, two part-time. Twenty-one hundred pages in *Mechanical Engineering* text and Transactions (including *Journal of Applied Mechanics* and Student Branch Bulletin), edited, styled, proofread, and published. Reports of Committees, Codes, etc., and special-meeting printing.

*Advertising and Sales Department* (*15*): Advertising manager, three sales representatives, seven on production of *Mechanical Engineering* advertising and Catalog including promotion, special service, layout, proof checking, publishing, and billing. Separate distribution list of 14,000 for catalog.
- Publications Sales (4): Sales of codes, reports, reprints, etc.

*Technical Committee Department* (*6*): Assistant Secretary and five assistants.
- Four hundred and thirty-nine Committees and subcommittees of Boiler Code, Power Test Codes, Standardization, Safety, and Research. Follow-up and publication of reports. Committee meetings, etc.
- Relations with American Standards Associations, International Electrotechnical Commission, etc.

*General Office* (*22*): Office manager in charge.
- Accounting (3): 15,000 individual accounts, 200 commercial accounts, 30,000 individual cash receipts annually, 5000 checks written annually.
- Shipping, stores, and mail (4): 250,000 pieces of mail received, 8400 orders for publications, badges, etc. handled.
- Addressograph and mimeograph (4): 16,000 address plates, 8000 changed each year; 30,000–40,000 address imprints per month; 50,000 copies from 250 stencils each month.
- Filing (2).
- General clerical and stenographic (8): master address record, 14,000 names, reception (800 visitors per month), stencil cutting, mail opening, etc.

C. E. Davies, *Secretary*

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BOUND copies of the complete Transactions of The American Society of Mechanical Engineers will be found in the libraries in the United States and other countries which are listed on the following pages.

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*Arkansas*

Fayetteville...... Engineering Library, Arkansas University

*California*

Berkeley......... Library, University of California
Long Beach...... Public Library
Los Angeles...... Public Library
  University of Southern California
Oakland......... Oakland City Library
  Teachers' Professional Library
Pasadena......... Library, California Institute of Technology
Santa Clara...... Library, University of Santa Clara
San Diego........ Public Library
San Francisco.... Public Library (Civic Center)
  Engineers Club of San Francisco
  Mechanics Institute
Stanford Univ.... Library, Stanford University

*Colorado*

Boulder.......... Library, University of Colorado
Denver.......... Public Library
Fort Collins...... Colorado State Agricultural College

*Connecticut*

Bridgeport....... Public Library
Hartford......... Public Library
New Haven...... Public Library and Yale University
Waterbury....... Silas Bronson Library

*Delaware*

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Wilmington...... Wilmington Free Institute

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Washington...... Scientific Library, U. S. Patent Office
  Library of Congress
  Bureau of Standards Library
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Gainesville....... University of Florida
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  Georgia School of Technology
Savannah........ Public Library

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  Western Society of Engineers
  Lewis Institute of Technology
  Library, Armour Institute of Technology
  Public Library of Chicago
Moline........... Public Library
Urbana.......... University of Illinois

*Indiana*

Evansville....... Public Library
Fort Wayne...... Public Library
Indianapolis...... Public Library and Indiana State Library
Notre Dame..... Library, University of Notre Dame
Terre Haute..... Rose Polytechnic Institute
West Lafayette... Library, Purdue University

*Iowa*

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Des Moines...... Public Library
Iowa City........ State University of Iowa

*Kansas*

Kansas City...... Public Library, Huron Park
Lawrence........ Library, University of Kansas
Manhattan....... Kansas State Agricultural College
Wichita.......... Wichita City Library

*Kentucky*

Lexington........ University of Kentucky
Louisville........ Speed Scientific School
  University of Louisville

*Louisiana*

Baton Rouge..... Louisana State University
New Orleans..... Howard Memorial Library
  Louisiana Engineering Society
  Public Library
  Tulane University

*Maine*

Orono........... University of Maine

*Maryland*

Annapolis........ United States Naval Academy
Baltimore........ Johns Hopkins University
  Engineers Club of Baltimore
  Public Library

*Massachusetts*

Boston.......... Engineering Societies of New England
  Northeastern University
  Boston Public Library
Cambridge....... Harvard University (Engineering Library)
  Massachusetts Institute of Technology
Fall River....... Public Library
Lowell.......... Lowell Textile Institute
Lynn............ Free Public Library
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Springfield....... Springfield City Library
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Worcester....... Worcester Polytechnic Institute
  Free Public Library

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  University of Detroit
East Lansing..... Michigan State College
Flint............ Public Library
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Duluth.......... Public Library
Minneapolis...... University of Minnesota
  Minneapolis Public Library (Engineering and Circulating Libraries)
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*Mississippi*

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Kansas City...... Public Library
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*Belgium*
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*Canada*
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- Cambridge ..... University of Cambridge
- Leeds ..... University of Leeds
- Liverpool ..... Public Library of Liverpool; Liverpool Engineering Society
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- Manchester ..... Manchester Public Libraries (Reference Library)
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- Newcastle-upon-Tyne ..... The North East Coast Institution of Engineers and Shipbuilders
- Sheffield ..... Sheffield Public Libraries

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- Cologne (Köln) ..... Universitäts- und Stadtbibliothek

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- Düsseldorf ..... Bücherei des Vereines deutscher Eisenhüttenleute
- Frankfort ..... Technische Zentralbibliothek
- Hamburg ..... Bibliothek der Technischen Staatslehranstalten
- Hanover ..... Bibliothek der Technischen Hochschule
- Karlsruhe ..... Bibliothek der Technischen Hochschule
- Leipsic ..... Stadtbibliothek
- Munich ..... Bibliothek der Technischen Hochschule; Bibliothek des Deutschen Museums
- Stuttgart ..... Bibliothek der Technischen Hochschule

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- Calcutta ..... Bengal Engineering College
- Poona ..... Poona College of Engineering
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*Ireland*
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*Italy*
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- Naples ..... Biblioteca della R. Scuola d'Ingegneria
- Rome ..... Biblioteca della R. Scuola d'Ingegneria; Consiglio Nazionale delle Ricerche presso il Ministero della Educazione Nazionale
- Turin ..... Biblioteca della R. Scuola d'Ingegneria

*Japan*
- Kobe ..... Kobe Technical College
- Tokyo ..... Imperial University Library; The Society of Mechanical Engineers
- Yokohama ..... Library of Yokohama

*Mexico*
- Mexico City ..... Asociacion de Ingenieros y Arquitectos de Mexico; Library of the Escuela de Ingenieros Mecanicos y Electricistas

*Norway*
- Oslo ..... Den Polytekniske Forening

*Poland*
- Warsaw ..... Bibljoteka Publicazna

*Porto Rico*
- Mayaguez ..... University of Porto Rico

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*Roumania*
- Bucharest ..... Scoala Polytechnica din Bucharest

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- Johannesburg ..... South African Institute of Engineers

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Svenska Teknologföreninger
Gothenburg......Chalmers Tekniska Institut

*Switzerland*

Zurich...........Bibliothek der Eidg. Technischen Hochschule

*Turkey*

Istanbul.........Robert College

*U.S.S.R.*

Kharkov.........Supreme Economic Council of Ukraine
Leningrad........Leningrad Polytechnic Institute
Moscow..........Supreme Council of National Economy
Tomsk..........Tomsk Polytechnic Institute

# Power Requirements and Mechanical Features of Textile-Printing Machines

By R. DeVERE HOPE,[1] NEWARK, N. J.

**The author presents in this paper the essential mechanical features and power requirements of textile-printing machines. Among the mechanical features the author discusses and compares the design and assembly of the principal parts of new- and old-type machines and gives the relation between printing speeds and types of fabrics being printed. Regarding power requirements, the paper includes (*a*) reasons for the application of electric-motor drives, (*b*) an analysis of a-c and d-c motor drives, and (*c*) the effect of both types of drive and their control apparatus on the product of the machines and on the operating cost of the plant. Operating test data obtained on textile-printing machines in normal operation are presented in the appendix.**

## Introduction

Textile printing may be defined as the art of applying colors to the surface of fabrics to form patterns of various designs. Printing is not a form of dyeing, as dyeing is a process by which the fabrics are completely saturated by passing them through a bath in which dyestuff and chemicals have been added in correct proportions and under proper temperature. In printing, heavier pigment colors are applied only to the surface of the goods.

Prior to the development of printing machines, there were other methods by which a color design could be transferred to cloth. Probably the oldest method was hand block printing. This is extremely slow and expensive, although very fine and artistic work has been done on silk and other fabrics, and some results were obtained which have never been reproduced by other methods. There is also the well-known present-day method of screen printing which produces artistic combinations, but due to the fact that the character of the patterns is limited, the work is all done by hand, which naturally makes the daily production low and the unit cost prohibitive in a great many cases.

The first printing machines were equipped with hardwood blocks instead of engraved copper rolls. While this was more rapid than hand printing, the results obtained were not as good as the hand work. This method is still used to some extent for printing on oilcloth, linoleum, and carpets.

Surface printing in relief and offset printing by machine has been almost universally adopted for wall paper, newsprint, and magazine work.

The early machines were driven by a belt and pulley, operating through a clutch. This drive remained for a long period but was never satisfactory. Whenever the printer found it necessary to jog the machine he performed the operation by slipping the clutch. If more than one speed were required it was necessary to stop the machine, change the lapping on the pulley, or change the pulley itself on the line or jack shaft.

Cone pulleys and idlers were used later to obtain variable speeds. While this arrangement was an improvement, it did not eliminate belt slippage. When the belts were tightened, the sudden jerk in starting not only racked the machine but also caused bad work, and occasionally resulted in breakage.

From the foregoing experience, it was only natural that the machine builders should decide that the proper drive for printing machines was one direct-connected and self-contained. A special slide-valve reciprocating steam engine known as the "angle" or "side hill" engine was finally built which provided a positive and variable drive. This met most of the requirements at the time and hundreds of such engines were sold, many of which are in operation today. Change of speed was accomplished by operating the steam throttle. This eliminated the jerk at starting and afforded continuous and smooth running. However, the high steam pressure necessary to operate this engine resulted in high maintenance costs and objectionable steam leaks. Another disadvantage of the steam engine resulted from the fact that the exhaust steam from the engine, which was used for drying, frequently carried cylinder oil, and thus prevented rapid elimination of water from the cans. In spite of these drawbacks, however, the individual steam-engine drive was considered very practical until superseded by the electric motor.

The earlier motor installations used belts for transmitting power between the motor and printing-machine shafts. However, these were replaced rapidly by gear and chain drives.

## Essential Features of Machines

The essential features which contribute more than anything else to the successful operation of textile-printing machines and which will result in perfectly registered and well-defined patterns on a large variety of styles and many different weaves of cloth are (1) the application of correct engineering principles, and (2) the assembly of the machine parts in such a manner as to eliminate interference in these parts.

Correct engineering principles of machine design must take strength and rigidity into consideration as well as the proper relationship between materials from which the various machine parts are made. All steel parts must be heat-treated to reduce to a minimum crystallization and failure by fatigue. Metallurgy and specimen testing play effective parts in proper design. The driving arrangement also must be strong and rigid. An improperly designed and poorly constructed drive is frequently responsible for delays and spoilage of many yards of cloth.

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Such a condition will discourage the best operator. In view of the fact that the machine must be operated over a wide range of speeds, it is essential that the drive be designed and built in such a manner as to have sufficient power available to make the operation positive and reliable at any speed.

In assembling the machine parts every facility must be provided for adjusting the pressure of nips, changing rollers, and color pans or boxes. Occasionally, the difficult task of changing the printing blanket must be undertaken.

The most important details of proper design and assembly are as follows:

1 The use of one size of roller which may be changed for another with little trouble. This is accomplished by arranging the nip with compound slides and large nip plates. Perfect variable traverse motion for the color doctors is also essential.

2 The use of bearings for the drives or bowl. Proper drives for simultaneously raising and lowering the bowl by means of screw-bevel worm gears naturally must be considered. The teeth of the star-and-box wheel should be machine-cut and of such shape as to allow for working either light or deep in the gear to suit the various sizes of rollers.

Printing machines are made in sizes varying in width from 36 in. to 50 in. and for printing from one color to sixteen colors. Based on rollers having a circumference of $16^3/_4$ in. they may be divided into three general classes: (1) Machines for printing on silk; (2) machines for printing on artificial fabrics; and (3) machines for printing on cotton.

Machines designed for printing on pure silk are generally geared for maximum speeds of from 50 to 60 yd per min. While both dry towers and dry cans are used, many printers believe that the circulation of hot air in the tower causes the pattern to stand out and produces a better product than when the drying is done on cans. Silk printing does not require a heavy set on the rollers. The slow maximum speed of 60 yd per min generally will only require a speed variation of 3 to 1. Some operators, however, demand a range of 4 to 1. The threading speed should be 50 per cent of the lowest operating speed, that is, 5 to 10 yd per min.

In printing acetates and other artificial cloth, the speed range is about the same as for silk. Heavier sets on the roller are necessary for the proper penetration of color, and consequently more power is required to operate the machines. Threading speeds for acetates must be as slow as for printing on silk, about 10 yd per min, for example, and the machine must be able to "inch" or "jog."

The first application of color by machine printing was on cotton. Cotton can be run at maximum speeds of 90 to 110 yd per min, and in the majority of cases, dry cans or cylinders are used for drying. On account of very high speeds a larger number of cans is required than found necessary for printing silk and artificial fabrics. About 10 to 15 per cent of the total power used for driving cotton-printing machines is consumed in driving the drying equipment. On light set, the running is similar to silk since in most cases through penetration is not attempted. Speed ranges are seldom less than 3 to 1 and in some cases printers insist on ranges of 5 to 1 and 6 to 1. The threading speed for cotton is usually 30 to 50 per cent of the lowest operating speed.

## Motor Equipment and Printing Speeds

Machines geared for producing printed cloth at the rate of 60 yd per min or less should not use motor speeds higher than 1400 rpm due to the high ratio of chain-gear drive. Drives requiring higher speeds, such as those necessary for printing cotton, may go to motor speeds of 1600 rpm without any mechanical difficulty.

The chief reason for the application of electric motors to textile printing machines is to obtain certain desirable features which were not obtainable with other types of drives. Quick stopping is not only desirable, but is an economical necessity. With direct-current motors this is accomplished by dynamic braking. With alternating-current motors, quick stopping is accomplished by either plugging or solenoid brakes. Plugging, or phase reversing, is in effect changing the direction of rotation of the motor and has been considered preferable to the solenoid method.

Predetermined speed setting is another desirable feature. This means that the machine operator may slow down or stop, then accelerate to the set predetermined operating speed and the machine will always be in register at that speed.

There is a wide variety of motors which have been found satisfactory for this type of work. The standard constant-torque type is frequently used, but actual tests indicate that the required power at low speeds is somewhat greater than a direct proportion to the decrease in speed. In other words, a 50 per cent reduction in speed would require more than a 50 per cent reduction in power.

Control circuits and equipment are now developed to such an extent that the machines are practically automatic. Stop-and-start switches are used to energize various relays in the circuit, and these relays start control apparatus working, which in turn regulates the motor and finally the speed of the machine. No machine could be considered properly equipped without having "stop," "jog or inch," "slow," and "fast" controls. When more than one control station is used a "safe" lock should be provided. Many painful and serious accidents have occurred due to the omission of this safety device.

With the earlier motor installations, difficulty was experienced in obtaining stable speed operations when low threading speeds were required. This, however, has been overcome in newer equipment by placing series resistance in the power circuit. This arrangement limits the tendency of series characteristics or reduced speed with increased load. The speed-load curve is practically flat except at the approach of excessively high loads, at which point the speed has a tendency to drop slightly. In some cases with very heavy sets, it is impossible to start the motor. Control equipment can be arranged so that part of the series resistance is cut out when such conditions occur. Recently, a new control circuit has been devised which will stabilize this condition to a large extent, even when threading at speeds as low as 20 per cent of normal low speeds.

TABLE 1 HORSEPOWER RATINGS FOR TEXTILE-PRINTING MACHINES

| No. of colors | Horsepower ratings for printing on— Silk | Artificial cloth | Cotton |
|---|---|---|---|
| 2 | 10 | 15 | 15 |
| 3 | 15 | 20 | 20 |
| 4 | 20 | 20 | 25 |
| 6 | 25 | 25 | 25 |
| 8 | 25 | 30 | 30 |
| 10 | 30 | 30 | 40 |
| 12 | 30 | 40 | 40 |
| 14 | 40 | 40 | 50 |
| 16 | 40 | 50 | 50 |

Horsepowers listed in Table 1 may be regarded as representative for textile-printing machines. They are proper averages taken from a large number of installations.

The comparison between old- and new-type printing machines given in Table 2 shows the progress which has been made in recent years. The new improvements came into effect with the advent of new color combinations and practically unlimited possibilities in pattern design. In the earlier days of calico printing, the machine would be set for a pattern combination and would often run at top speed for several days, during which time the operator's chief duties were to add color to the pans and see that the doctors were properly adjusted.

TABLE 2 COMPARISON OF OLD- AND NEW-TYPE MACHINES

| | Old design | New design |
|---|---|---|
| 1 | Fitting gears were plain cast iron, with no safety flanges. Bronze worm gears and no locking devices. | Safety-type semi-steel gears, with protecting flange. Five-thread worms with renewable wearing rings. Steel worm gear with locking devices on the nuts. |
| 2 | Babbitt or bronze liners in the driving box. | Antifriction-bearing arrangements for self-aligning and Alemite lubricated. |
| 3 | Traverse motion driven by two pairs of bevel gears from the cylinder shaft. | Traverse motion much simplified driven by chain and sprockets from main drive shaft. Facilitates greatly the changing of a blanket. |
| 4 | Traverse rods with brass connections, and no means of taking up wear. This condition sometimes caused chattering and lost motion in the doctors. | Universal ball-and-socket design with adjustment to take up wear, and lost motion, and so induce a smooth even motion in the doctors. |
| 5 | Blanket roll was sometimes used to drive the traverse motion, and this drive was always carried in plain open bearings. | An ingenious design incorporated in the new traverse motion, which is carried in internal antifriction bearings. |
| 6 | Leader rolls of wood running in open-type bearings. | All rolls contacting the blanket now have turned-steel pipe bodies. The rolls contacting printed goods or greys have brass tube bodies. Each roll has antifriction bearings in Alemite lubricated, self-aligning housings. This condition causes less strain on blanket, goods, and greys. |
| 7 | The drag roll is usually the first nip. This means tying up a mandrel and a roller, and deprives the printer of the use of the first nip for color work. | Lightweight drag roll with heavy steel body is located above No. 1 color nip. |
| 8 | Mandrel collars take thrust by metal-to-metal contact, destroy lubrication, and cause excessive wear on mandrel liners. | External antifriction collars take the thrust in a more efficient manner. |
| 9 | Color pans have perishable wooden base-boards. | Color pans have steel base-plates which not only last indefinitely, but give better visibility to the other color pans and doctors on the machine. |
| 10 | Mandrels are mostly carbon steel with plain turned bodies. | Mandrels are of chrome-nickel or chrome-vanadium steel, giving longer life and reducing deflection. The bodies are ground accurately so that rollers are easier to remove. |
| 11 | Star gears of assorted sizes are required to match different sizes of rollers. | The later method is to use the STS, similar to Rice, Barton & Fales, gear system, which has standard gear teeth, and perfect gear mesh. This eliminates the handling of star gears and makes it possible to have a range of 10 in. on the roller circumference. |
| 12 | Driving units frequently used belts or gears, and many such drives take up more space than the machine itself. | The so-called "high-drive" is a most compact arrangement and permits new machines to be placed so as to economize in floor area and yet give ample working space around the machine. |
| 13 | Back-riggings usually were constructed crudely, and the drying tower was sometimes nothing more than a box filled with rollers and steam coils. | The improvements which have been made in new drying equipment are numerous. The back rigging is constructed of heavy steel frames and equipped with adjustable brush roll and dust box. All turning elements are equipped with ball bearings. Many drying towers are equipped with properly conditioned air and it is practicable to dry goods at the rate of 90 to 100 yd per min. The rollers supporting the cloth passing through the drier are carried on ball bearings which are located on the outside of the drier. |

A few years ago engineering studies of machine operations were made and it was found that the actual running time was about 33 per cent of the working day. The remaining 67 per cent was consumed in changing patterns. Naturally, greater speeds, sometimes higher nip pressures, and above all simplification of mechanical details, were demanded. Many old machines were scrapped because they could not meet the requirements of the changed conditions. The products of the improved machine are far superior, the rate of production is faster, and maintenance costs have been reduced greatly.

The speed at which a printing machine can economically produce goods depends upon a number of factors, such as the number of colors to be printed, texture and width of material, depth of engraving, the set on the rollers necessary for satisfactory printing, and the additional load which the machine itself must pull, such as drying cans, batches reeling off machine, and endless blankets. The actual production may vary from 30 yd per min for silk to 130 yd per min for narrow cotton. An average of 40 yd per min for silk and artificial fabrics and 100 yd per min for cotton should be proper for machines equipped with not more than eight colors. In a plant operating with 10, 12, 14, and 16 color machines, the output would probably be about 75 per cent of these figures.

### Power Requirements and Electric Drives

The power requirements for printing machines are very erratic and practically impossible to predict with any degree of accuracy. Therefore, it is necessary to use a motor of sufficient capacity for maximum power demand. The average load is usually about 40 to 60 per cent of the demand. Many machines are undermotored because proper consideration was not given initially to the selection of the motor best suited for the work.

Present-day printing requires a motor of variable speed, and high starting torque. While the power varies with the speed, the torque changes widely due to many other conditions, such as the number of rollers and pressure. Table 3 shows how the power varies only with change of pressure on the nips.

TABLE 3 POWER VARIATIONS WITH DIFFERENT NIP PRESSURES

| No. of colors | Yd per min | Hp |
|---|---|---|
| 5 | 45 | 11.5 |
| 5 | 45 | 23.0 |
| 7 | 40 | 23.0 |
| 7 | 46 | 11.2 |

It is of historical interest to record that the first application of electric motors to textile-printing machines in the United States was made at the plant of the United States Finishing Company, Pawtucket, R. I., about 42 years ago.

### Types of Electric Drive

There are four principal methods of electrically driving textile-printing machines. These are: (1) The Ward Leonard direct-current method, (2) the multivoltage direct-current method, (3) the variable-speed direct-current method, and (4) the variable-speed alternating-current (BTA) method.

*Ward Leonard Method.* This system consists of a direct-current motor, a direct-current generator and exciter, and controlling device. The motor-driven exciter furnishes separate excitation for the shunt fields of both the generator and the motor. The motor field excitation is constant, while that of the generator is varied by means of a rheostat placed in series with the field current. By varying the generator field resistance, the voltage is changed and this produces a corresponding change in the speed of the motor.

This method is outstanding where a wide range of speeds is employed. It is doubtful, however, whether full advantage can be taken of these excellent characteristics. Under ordinary circumstances either the adjustable-speed direct-current motor or the variable-speed brush-shifting alternating-current motor has sufficient speed range for the majority of printing-machine applications.

*Multivoltage Method.* In this system, as the name implies, the

motor speed range is obtained by impressing upon the motor voltages of different values. In this country, the method usually employs a generator operating at 250 volts and a three-unit balancer. These units are designed for 60, 80, and 110 volts. From this arrangement fixed-voltage steps of 60, 80, 110, 140, 190, and 250 volts are provided. Four wires are carried to each motor through controllers. This arrangement gives a speed range of 6 to 1. There are only a very few of these multivoltage systems still being used and there seems to be no valid reason for their installation. The equipment is bulky, complicated, and expensive.

*Variable-Speed Direct-Current Method.* Wherever direct current is available in a mill, the application of the shunt-wound direct-current variable- or adjustable-speed motor is the most suitable drive for printing machines. With the addition of the commutating or interpole, the stability and commutating characteristics are so much improved that it is now possible to get a range of speed variations sufficiently wide to meet most of the textile-printing conditions. This variation is achieved both by shunt-field and armature control.

The speed changes may be obtained either by drum controllers or by automatic or semiautomatic predetermined speed controllers operated by push buttons. The equipment for semiautomatic and predetermined speed control is assembled and mounted on slate panels housed in steel panel boxes.

*Variable-Speed Alternating-Current Method.* Several years ago the General Electric Company acquired the American rights to manufacture an adjustable-speed alternating-current motor known as the BTA motor. This enables printing plants which have only alternating-current supply to use electric drives. While this motor is not as flexible as the direct-current motor, 3-to-1, and in some cases 4-to-1, speed ranges are obtainable. This range should be sufficient for printing and other finishing requirements. These motors can be procured for either two- or three-phase service. The control equipment for BTA motors may be either automatic or semiautomatic, similar to that used for installations of direct-current motors.

A careful comparison of certain features of the BTA equipment with direct-current installations indicates that the efficiencies throughout the entire range of speed are high. Other characteristics, however, are not so satisfactory. The starting torque is lower, and the speed curve shows a drop of from 10 to 25 per cent with increased load. This drop is much greater than the drop in the interpole shunt motor equipped with stabilizing winding.

The power factor of the BTA motor is very high except at low speeds, although at such speeds it is about 60 per cent; higher than other types of alternating-current motors at similar speeds. The leading power factor found at high speeds is a highly desirable condition in territories where utility companies penalize for low power factors.

Maintenance cost is approximately the same with either the direct-current shunt or the BTA alternating-current motor. Most of the electrical maintenance items in printing-machine installations are in the switching gear and control apparatus rather than in the motors themselves. The reason for this is that the motors will carry higher overloads than the controls. Some cases are recorded where excessive interruptions have been improved by replacing contactor relays and other control equipment with equipment of higher capacity.

The initial investment for direct-current-motor drives is less than that for BTA equipment. In cases where only alternating current is available, motor-generator sets or rotary converters may be installed to change the alternating current to direct current to supply the motors. However, it is not economical to install a motor-generator set unless the plant has at least three printing machines, at which point the investment is about the same as that for BTA motors. When there are more than three machines, the motor-generator set and direct-current motors are cheaper.

Other types of alternating-current motors, such as the induction, squirrel-cage, and the wound-rotor types, have been used occasionally, but for general practice these types are not regarded as being satisfactory for textile-printing machines.

Observation of a large number of machines discloses the fact that in most cases the limiting factor which controls the speed of production is that of drying. Most drying processes are still done on dry cans or cylinders. While cans may be suited fairly well for cotton, the acetate and celanese materials are better when dried in machines utilizing the principle of rapidly moving hot air. Some companies have made or purchased drying equipment using the basic principle of impinging proper quantities of conditioned air for drying purposes.

It should be remembered, of course, that drying is essentially a heat-consuming process and the heat necessary to change the moisture into vapor must be supplied solely from the air. The rate of drying will then depend mainly upon the rate at which heat is transferred to the moisture. It is the author's opinion that many plants can increase the production from printing machines 35 to 40 per cent by installing modern drying equipment designed better to meet present-day requirements.

## Other Power Requirements in the Textile-Printing Plant

While power applications for other machines and equipment in a finishing plant are just as important as those previously discussed, the requirements are of such a character that standard-type motors and drives can be used.

The squirrel-cage induction motor is well adapted for a large variety of applications. First cost of these motors is lower than other types and maintenance expense is also less. It is necessary to estimate carefully the power requirements in order not to overmotor the machine, as such a condition would result in a low power factor which would add unduly to the power cost. Table 4 shows the relation between the power factor and load on three-phase squirrel-cage motors.

TABLE 4 RELATION BETWEEN POWER FACTOR AND LOAD ON THREE-PHASE SQUIRREL-CAGE MOTORS

| | | | One-half load | | Full load | |
|---|---|---|---|---|---|---|
| Hp | Poles | Voltage | Kw | Pf[a] | Kw | Pf[a] |
| 1 | 4 | 220 | 0.53 | 55 | 0.91 | 83 |
| 2 | 4 | 220 | 0.96 | 78 | 1.80 | 86 |
| 5 | 4 | 220 | 2.22 | 76 | 4.35 | 87 |
| 10 | 4 | 220 | 4.36 | 81 | 8.70 | 88 |
| 15 | 4 | 220 | 6.16 | 85 | 13.30 | 92 |
| 20 | 4 | 220 | 8.09 | 88 | 16.83 | 91 |
| 25 | 4 | 220 | 10.28 | 90 | 20.95 | 92 |
| 25 | 8 | 220 | 10.62 | 75 | 21.00 | 86 |
| 30 | 4 | 220 | 12.10 | 91 | 24.60 | 93 |
| 40 | 4 | 220 | 16.32 | 86 | 32.61 | 92 |
| 50 | 4 | 220 | 20.00 | 93 | 40.50 | 93 |
| 75 | 6 | 220 | 30.70 | 80 | 61.00 | 88 |
| 100 | 8 | 220 | 41.50 | 80 | 83.20 | 90 |
| 150 | 8 | 220 | 55.95 | 84 | 120.00 | 92 |
| 200 | 10 | 220 | 83.50 | 73 | 163.20 | 86 |

[a] Power factor, per cent.

An inspection of Table 4 shows the necessity of maintaining loads on induction motors to at least 50 per cent of the rated capacity in order to secure a good power factor. At this point it may be expedient to investigate the practical application of power factors. One definition of power factor gives it as the ratio of electric power in watts to the apparent power in volt-amperes, or power factor = watts/$EI$. Another definition gives the power factor as being equal to the cosine of the angle between the vector representing kilowatts and the vector representing kilovolt-amperes. A third definition, and the one which the author believes to be the most practical, gives the power factor as the ratio of the current producing power to the total current,

that is, power factor = power current/total current, wherein the total current is the resultant of the magnetizing current and the power current.

The chief cause of a low power factor is underloaded induction motors, transformers, and other induction apparatus placed in an alternating-current circuit. The reason this type equipment causes a low power factor is the fact that magnetizing current is required. This current does no work but is necessary for the proper operation of equipment of this nature. The magnetizing current remains almost constant irrespective of the load. From this discussion it is seen that additional investment is required in equipment in any system where the power factor is low.

There are three practical methods by which the power factor in an alternating-current system can be improved. They are as follows:

1 Apply motors of such capacity as to operate as nearly as possible at full load. Wherever machines are overmotored, which is the usual tendency with induction-motor applications, the motor should be replaced by one of smaller size.

2 Sometimes a synchronous motor can be used. This type motor not only does useful mechanical work but corrects the power factor at the same time.

3 When it is desirable to improve a low power factor without using equipment to carry mechanical load, the synchronous rotating condenser or static condenser may be used.

In all power applications, the most important consideration should be overall economy. This introduces a study of continuity of service and facilities for meeting peak demands as well as economical overall operations. While efficiency of motors and generators and other electrical and mechanical driving equipment cannot be ignored, it should receive less consideration than that of continuity.

It is found frequently that large investments in plant equipment and spoilage of merchandise occur as a result of erroneous decisions having been made in the selection of drive units. In most cases, such wrong applications are due to an overzealous incentive to consider purely the efficiency of the drive unit instead of considering the overall efficiency of either the entire plant or a group of machines which depend for proper and continuous performance on the individual driving units.

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# Appendix

This appendix is a compilation of test data in tabular form as obtained from textile-printing plants. The data in Table 5 were obtained from typical applications of direct-current machines selected at random in normal operation. Table 6 contains data obtained from two different plants and correlated to show power requirements of BTA and direct-current motors for operating machines at the same general cloth speed. Table 7 is a compilation of data from printing machines manufactured by the Rice, Barton & Fales, Inc., Worcester, Mass., operated by the various motors listed in the table.

All of the machines, the data on which are given in Table 5, were operated by shunt-wound interpole motors, and were controlled by Cutler-Hammer starting equipment. This starting equipment consisted of control units and push-button stations for "inch," "slow," "fast," and "stop" control. A field rheostat was used in conjunction with the "fast" control. The control system is a particular arrangement for textile-printing work and is explained as follows:

1 The "inch" button closes the contactors at the "slow" position but does not energize any holding coils and, therefore, allows the machine to run only as long as this button is being pressed. This provides the operator with a means of "inching" the machine. The speed is the same as when the "slow" button is contacted.

TABLE 5 OPERATING DATA OF DIRECT-CURRENT TEXTILE-PRINTING MACHINES

| Factory mach. no. | No. of colors | Type of cloth | Volts | Amp | Elec. hp | Yd per min[a] | Motor data[b] | Machine description |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Cotton handkerchief | 252 | 33 | 11.1 | 95 | 10–15 hp, type T 230 v, 39–58 amp 400–1600 rpm frame 185T | Old English for 4 colors with 15-cylinder drier. |
| | | | 252 | 26 | 8.8 | 74 | | |
| | | | 250 | 23 | 7.7 | 64 | | |
| | | | 250 | 16 | 5.4 | 32 | | |
| 2 | 2 | 95 | 252 | 30 | 10.1 | 16 | 10–15 hp, type T 230 v 400–1600 rpm 39–58 amp frame 185T | Mfd. by Phoenix Fdy. for 3 colors with 2 large and 6 small cylinder driers. |
| | | | 252 | 18 | 6.1 | 33 | | |
| | | | 250 | 24 | 8.0 | 46 | | |
| | | | 250 | 27 | 9.0 | 52 | | |
| | | | 252 | 30 | 10.1 | 56 | | |
| 3 | 2 | 95 | 246 | 38 | 13.6 | 75 | 15–20 hp, type T 230 v 58.5–74 amp 400–1600 rpm frame 230 | Mfd. by Textile Fin. Mach. Co. for 4 colors with 6 large cylinder driers. |
| | | | 250 | 40 | 16.9 | 82 | | |
| | | | 250 | 32 | 12.5 | 66 | | |
| | | | 247 | 20 | 21.0 | 35 | | |
| | | | 244 | 24 | 7.3 | 43 | | |
| 4 | 3 | 95 | 250 | 26 | 8.7 | 34 | 15–20 hp, type T 230 v, 58.5–74 amp 400–1600 rpm frame 230 | Mfd. by Rice, Barton & Fales for 4 colors with 13 can drier. |
| | | | 250 | 34 | 11.4 | 47 | | |
| | | | 246 | 47 | 13.2 | 62 | | |
| | | | 246 | 57 | 18.8 | 77 | | |
| 5 | 2 | 68 | 246 | 19 | 6.3 | 28 | 15–20 hp, type T 230 v, 58.5–74 amp 400–1600 rpm frame 230 | Mfd. by Textile Fin. Mach. Co. for 4 colors with 15-cylinder drier. |
| | | | 246 | 23 | 7.6 | 35 | | |
| | | | 249 | 26 | 8.7 | 54 | | |
| | | | 250 | 37 | 12.4 | 61 | | |
| ... | 4 | 100 | 254 | 46 | 15.6 | 43 | 15–20 hp, type T 230 v, 58.5–74 amp 400–1600 rpm frame 230 | Mfd. by Textile Fin. Mach. Co. for 4 colors with 15-cylinder drier. |
| | | | 255 | 60 | 20.5 | 55 | | |
| | | | 250 | 70 | 23.4 | 64 | | |
| 6 | 4 | 68 | 242 | 42 | 13.7 | 47 | 20–25 hp, type T 230 v 77–96 amp 400–1600 rpm frame 262 | Mfd. by Textile Fin. Mach. Co. for 6 colors with 14-cylinder drier. |
| | | | 242 | 52 | 16.9 | 60 | | |
| | | | 246 | 38 | 12.5 | 19 | | |
| | | | 246 | 64 | 21.0 | 71 | | |
| | | | 246 | 22 | 7.2 | 24 | | |

[a] Cloth speed.
[b] Reliance Electric & Manufacturing Company motors.

TABLE 6 POWER REQUIREMENTS OF BTA AND DIRECT-CURRENT MOTORS FOR OPERATING MACHINES AT SAME CLOTH SPEED

| No. of colors | Cloth speed, yd per min | Horsepower BTA | Horsepower Direct current |
|---|---|---|---|
| 4 | 64 | 19.0 | 21.0 |
| 4 | 78 | 23.5 | .. |
| 4 | 70 | .. | 23.0 |
| 1 | 32 | .. | 5.4 |
| 1 | 48 | 6.4 | .. |

TABLE 7 OPERATING DATA OF A-C AND D-C TEXTILE-PRINTING MACHINES[a]

| Test no. | Motor data | Machine no. | Volts | Amp | Input, kw | Rpm | Yd per min | No. colors | Output, hp | Power factor, % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | BTA-326; 8 pole; 30/10 hp 1250/415 rpm; 550 v 30.5/15.5 amp; No. 4,560,778 | 610 (8 colors) | 565 | 11 | 9.6 | 440 | .. | 6 | 9.25 | 89.0 |
| | | | 565 | 22 | 21.0 | 1180 | 64 | 6 | 21.60 | 97.5 |
| | | | 565 | 22 | 22.0 | 1250 | 70 | 6 | 22.80 | 99.0[b] |
| 2 | BTA-532; 8 pole; 35/11.6 hp 1250/415 rpm; 36.5/28 amp 550 v; No. 5,230,533 | 728 (8 colors) | 565 | 15 | 7.4 | 750 | 48 | 1 | 6.35 | 50.5 |
| 3 | BTA-526; 8 pole; 30/10 hp 1250/415 rpm; 30.5/16.5 amp 550 v; No. 4,560,778 | 626 (6 colors) | 570 | 20 | 11.6 | 540 | 28 | 4 | 11.70 | 59.0 |
| | | | 565 | 20 | 18.4 | 1020 | 64 | 4 | 19.00 | 94.0 |
| | | | 565 | 22 | 22.6 | 1200 | 78 | 4 | 23.50 | 97.5[b] |
| 4[c] | RF-12; 20/30 hp; 230 v 525/1500 rpm; 75/114 amp No. 1,337,091 | 562 (8 colors) | 140 | 70/40 | ... | .. | .. | 5 | ... | . |
| | | | 242 | 42 | 10.2 | 550 | 25 | 5 | 11.20 | 58.0 |
| | | | 242 | 54 | 13.1 | 720 | .. | 5 | 15.00 | 58.0 |
| | | | 240 | 75 | 18.0 | 1050 | .. | 5 | 21.00 | 58.0 |
| | | | 236 | 114 | 26.9 | 1560 | 68 | 5 | 31.40 | 58.0 |
| 5[c] | RF-12; 20/30 hp; 230 v 525/1500 rpm; 75/114 amp No. 1,337,092 | ... (6 colors) | 240 | 26 | 6.24 | 400 | .. | 1 | 6.17 | 58.0 |
| | | | 240 | 40 | 9.6 | 800 | 54 | 1 | 10.60 | 58.0 |
| | | | 240 | 45 | 10.8 | 900 | 62 | 1 | 12.20 | 58.0 |
| | | | 240 | 50 | 12.0 | 1090 | .. | 1 | 13.70 | 58.0 |

[a] All data reported in this table were obtained on Rice, Barton & Fales machines.
[b] Leading power factor.
[c] Voltages and currents given represent those at the armature.

NOTES:

In test No. 1 the machine was producing dry goods; the color rolls had a medium set; the cylinder width was 45 in.; the back-rigging consisted of seven dry cans of 23 in. diameter and four dry cans of 5 ft diameter; there were no goods in the machine when the first reading was taken; the 1250-rpm reading was the maximum speed obtained.

In test no. 2 the machine was printing mercerized lawn; the color roll had a medium set; the cylinder width was 45 in.; the back-rigging consisted of seven dry cans of 23 in. diameter and four dry cans of 5 ft diameter; the speed of the machine could not be varied.

In test no. 3 the machine was printing cretonne; the color-roll set was fair (more than medium); the cylinder width was 45 in.; the back-rigging consisted of six dry cans of $23^1/_2$ in. diameter and four dry cans of 5 ft diameter.

In test No. 4 cotton material was being printed; the color-roll set was medium; the cylinder width was 44 in.; the back-rigging consisted of five 5-ft dry cans; the control consisted of a drum controller and resistor; the machine was warm, but it started on an armature current of 70 to 85 amp.

In test no. 5 the machine was printing a fine-point shirting top; the set of the color roll was very heavy; the cylinder width was 42 in.; the back-rigging consisted of six dry cans of $23^1/_2$ in. diameter and four dry cans of 5 ft diameter; the control consisted of a drum controller and resistor.

2 The "slow" button closes the contactors (in the same manner as the "inch" button) with a resistor in series with the armature and a resistor across the armature. These are held in place by a holding-coil circuit. This gives a very slow speed which cannot be varied by the operator.

3 The "fast" button operates contactors which remove the armature shunt and cut out the armature resistor, after which the field resistor is inserted. This permits the operator to vary the speed of the machine throughout its normal range.

4 The "stop" button breaks the contactor holding coil, cutting the power supply from the machine and putting it across a resistor. Thus the field remains energized and results in dynamic braking.

With this control system, the armature resistor runs the energy demand of the machine up at slow speeds but gives a threading speed which is independent practically of the load. This effect is necessary for textile printing. By this means a motor with a variable speed between 400 and 1600 rpm can be operated with speed regulation approximately 25 per cent below minimum speed.

The use of interpole shunt motors with the control system outlined gives a printing-machine operator a finger-tip control over a wide speed range plus the advantage of "inching."

TABLE 8 TYPICAL CONNECTED DIRECT-CURRENT LOAD AND POWER SUPPLY

| | |
|---|---|
| Total connected load, hp | 176 |
| Total connected load in use daily, maximum, hp | 151 |
| Constant load, maximum as connected, hp | 36 |
| Total horsepower, maximum of daily load in use for printing machine, hp | 115 |
| Rated output of motor-generator set, hp | 100 |
| Ratio of capacity of motor-generator set to connected load (100/151) | 0.66 |
| Maximum load ordinarily observed, includes all machines, hp | 68 |
| Usual load range, hp | 50–68 |
| Ratio of running load to capacity of motor-generator set (68/100) | 0.68 |

NOTE: The usual run of work in textile-printing plants is such that the machines are producing with a less number of colors than they were motored for, and therefore for most of the working period the machines are overmotored.

In Table 8 are given typical data for textile-printing plants with direct-current load and power supply.

# The Torque and Thrust of Small Drills Operating in Various Metals

By O. W. Boston[1] and W. W. Gilbert,[2] Ann Arbor, Mich.

**This paper presents the results of a detailed study in which torque and thrust were recorded when drilling with small drills ranging from 1/8 in. to 1/2 in. in diameter. The influence of cutting speed on the value of torque and thrust when cutting a low-carbon steel with a 1-to-16 emulsion is shown to be appreciable at the lower speeds but negligible in the higher ranges of speeds. The torque and thrust values are shown to be reduced slightly for increased values of helix when drilling low-carbon steel with drills of 5/32 in. diameter having helix angles ranging from 21 to 40 deg. It is shown that the greatest factor of safety, as represented by breaking strength over operating torque, is obtained when the helix angle is about 36 deg.**

**Another series of tests reported in this paper shows that the torque and thrust are increased as the web thickness of 23-deg helix drills of 5/32 in. diameter is increased from 0.029 to 0.043 in. The factor of safety is reduced as the web thickness is increased.**

**Extensive data for torque and thrust for drill sizes ranging from 1/8 in. to 1/2 in. are given when drilling nine ferrous and nonferrous metals. These data are then correlated with corresponding torque and thrust values for the same metals previously reported (1, 2, 3,)[3] for larger diameter drills.**

The first part of this paper describes and gives the results of an investigation relating to the torque and thrust developed by twist drills ranging from $^1/_8$ in. to $^1/_2$ in. diameter when drilling five steels, two irons, and two nonferrous metals with a 1-to-16 emulsion.

The influence of different values of helix angle, web thickness, cutting speed, and feed on the torque and thrust and drilling performance is determined. The value of torque and thrust as a function of drill diameter and feed for industrial use is then determined. Lastly, these data for small drills are correlated with corresponding data presented in earlier papers (1, 2, 3).[3] Charts showing the value of torque and thrust for various feeds and commercial drills ranging in diameters from $^1/_8$ in. to $1^1/_2$ in. are then presented.

## Material and Equipment Used in Making the Test

*The Materials Cut.* Nine materials, consisting of cast aluminum, free-cutting brass, gray cast iron, malleable cast iron, S.A.E. 3150 steel, S.A.E. 1020 steel, S.A.E. 1035 steel, 0.97 per cent carbon tool steel, and free-cutting screw stock S.A.E. 1112 steel, were cut. These materials have been described previously (3). Table 1 lists these metals and gives analyses and physical properties.

*The Drill Press.* A modern self-contained drill press, illustrated in Fig. 1, was used in conducting the experiments on small drills. This press had a capacity of $1^1/_4$-in. drills in steel. It had a self-oiled geared head providing six selective speeds of 143, 225, 354, 575, 900, and 1415 rpm and six power feeds of 0.004, 0.006, 0.009, 0.014, 0.021, and 0.031 in. per revolution.

*The Dynamometer.* When testing the large drills, a high-capacity hydraulic type of dynamometer (3) was used which would record accurately the torque and thrust for drills above $^1/_2$ in. diameter. In these small-drill tests a new type of dynamometer was used, sensitive enough to record the torque and thrust of drills as small as $^1/_8$ in. diameter. It would record, as its maximum capacity in steel, the torque and thrust for $^1/_2$-in. drills. The two dynamometers, therefore, covered drill sizes ranging from $^1/_8$ in. to 2 in. diameter.

The small dynamometer consisted of a base which was fastened to the drill-press table, an intermediate plate used to record the thrust, and a top plate or table which supported the work and recorded the torque. The base carried two solid pivot points and one movable point, which supported the intermediate plate. The movable point was connected through amplifying levers to a pen for recording the thrust. The amplifying lever acted against a small cantilever spring and allowed a small deflection of the table proportional to the force applied. The three pivot points on the base formed a three-point support for the intermediate plate. The top of the intermediate plate was provided with a large annular groove filled with balls to support the upper plate or table. This allowed the upper plate to rotate without friction. The circular motion caused by the torque of the drills was transmitted by a second amplifying lever to a torque-recording pen. This lever for measuring torque acted against a second cantilever spring to avoid rotation of the work. A plate arranged to move vertically carried the paper on which the torque and thrust were recorded. This plate was attached to the spindle by a small wire and moved vertically downward while the drills were penetrating the work. This dynamometer was carefully calibrated for torque and thrust, and a celluloid scale was prepared so that the true values of the torque and thrust could be read quickly from the charts obtained.

*The Drilling Tests.* All drills with unpolished flutes were sharpened before each test on a small drill-grinding machine so that the shape could be reproduced in subsequent sharpenings. Before running any tests, each newly ground drill was used to

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[2] Instructor in metal processing at the University of Michigan. Jun. A.S.M.E.

[3] Numbers in parentheses refer to similarly numbered references at the end of the paper.

Contributed jointly by the Special Research Committee on Cutting of Metals and Machine Shop Practice Division and presented at the Annual Meeting of The American Society of Mechanical Engineers held at New York, N. Y., December 2 to 6, 1935.

Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until April 10, 1936, for publication at a later date.

TABLE 1 THE NINE METALS USED IN THE DRILLING TESTS (3)[a]

| Bar section, in. | Material | Heat-treatment | Analysis | | Hardness numbers: Rockwell 100 kg, $^1/_{16}$-in. ball | Hardness numbers: Brinell | Physical properties: Yield point, lb per sq in. | Physical properties: Ultimate strength, lb per sq in. | Physical properties: Elongation, per cent in 2 in. |
|---|---|---|---|---|---|---|---|---|---|
| $1^1/_2 \times 2$ | Aluminum alloy S.A.E. 33 | Chill cast | 91.00 Al<br>1.00 Impurities | 8.00 Cu | 37.5 | 70 | ... | ... | ... |
| $1^3/_4 \times 1^3/_4$ | Leaded free-cutting brass | Extruded and drawn | 61.75 Cu<br>3.21 Pb | 35.00 Zn<br>0.04 Fe | 66.0 | 100 | 34700 | 51800 | 43.5 |
| $1^3/_4 \times 4$ | Cast iron | Cast | 3.44 C<br>0.986 Ni | 2.62 Si<br>0.478 Mn | 83.5 | 179 | ... | ... | ... |
| $1^3/_4 \times 4$ | Malleable cast iron[b] | $40^1/_4$ hr to 1550 F<br>48 hr at 1550-1625 F<br>$64^1/_2$ hr to cool to 1200 F | 2.46 C<br>0.163 P<br>0.071 S | 1.00 Si<br>0.26 Mn | 71.0 | 137 | ... | ... | ... |
| $2 \times 6$ | S.A.E. 3150 steel | Annealed | 0.50 C<br>0.62 Cr<br>0.68 Mn | 1.16 Ni<br>0.022 P<br>0.023 S | 86.0 | 196 | 66140 | 114200 | 26.00 |
| $1^3/_4 \times 4$ | S.A.E. 1020 steel | Annealed | 0.22 C<br>0.52 Mn | 0.011 P<br>0.026 S | 65.0 | 131 | ... | ... | ... |
| $1^3/_4 \times 4$ | S.A.E. 1035 steel | Annealed | 0.38 C<br>0.017 P<br>0.031 S | 0.18 Si<br>0.53 Mn | 75.0 | 156 | ... | ... | ... |
| $4 \times 6$ | Carbon tool steel | Annealed | 0.97 C<br>0.025 P<br>0.027 S | 0.10 Si<br>0.31 Mn | 85.0 | 152 | 36500 | 77350 | 30.0 |
| $1^1/_2 \times 1^1/_2$ | S.A.E. 1112 steel | Cold drawn | 0.09–0.13 C<br>0.70–0.90 Mn | 0.08–0.40 P<br>0.085–0.12 S | 89.5 | 217 | ... | ... | .. |

[a] Number in parentheses refers to similarly numbered reference at the end of the paper.
[b] The analysis given is for hard iron.

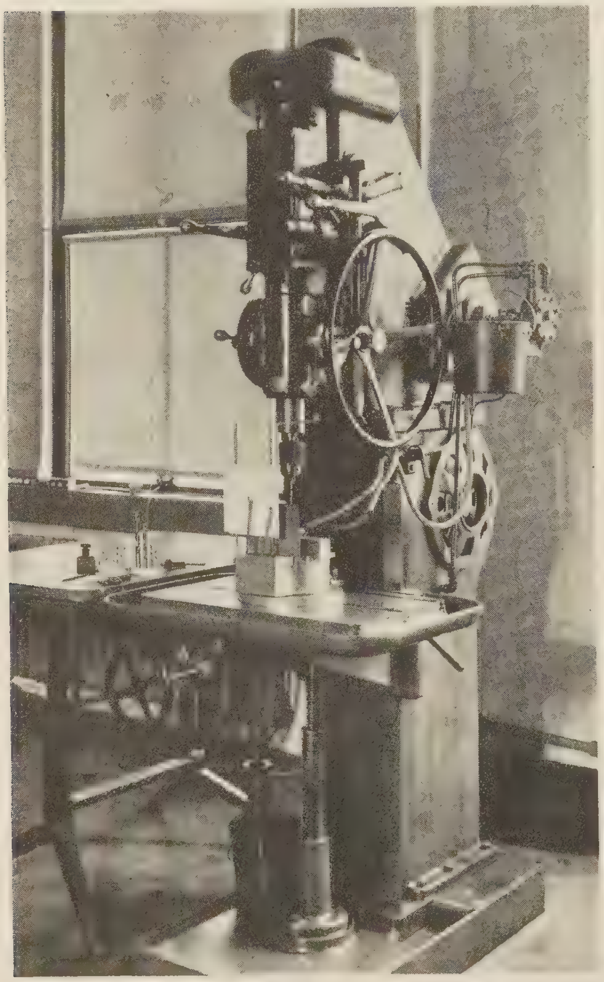

FIG. 1 THE DRILL PRESS, DYNAMOMETER AND EQUIPMENT USED IN TESTING THE SMALL DRILLS

drill one hole to remove any "feather" edge. All holes were drilled to a predetermined depth of $^1/_2$ in. when the feed was automatically disengaged and the spindle returned to the top of its stroke. All holes drilled were dead end, rather than being drilled through the work. Torque and thrust values were read from the charts for a hole depth of $^3/_8$ in. No drill bushings were used in the tests, as it was found they were not needed and might influence the values because of chip interference.

The cutting-fluid system of the press was replaced with a gravity-feed system so that a $^3/_{32}$-in. stream of an emulsion made of one part of a soluble oil and sixteen parts of distilled water was directed on the top of the work about the drill. The discharge head was 16 in., and 1 quart of the emulsion was discharged per minute.

*The Charts.* It was found that, when drilling particularly with small drills, the value of the torque and thrust was influenced appreciably many times by chips forming in the flutes. Fig. 2 shows the torque and thrust charts when drilling in a free-cutting brass with a 30-deg helix drill $^3/_8$ in. diameter for each of three feeds of 0.004, 0.006, and 0.009 in. For this relatively large drill in this free-cutting material, the chips were so well broken up and disposed of that the values of torque and thrust are seen to remain practically constant while drilling the $^1/_2$-in. deep holes. Fig. 3, however, shows similar charts of small $^3/_{16}$-in. drills operating in soft steel. For the finer feeds, the chips appear to be well disposed of, and very little increase in torque or thrust is noted as the hole increases in depth. For the 0.009-in. feed, however, chip disposal becomes important, as is indicated by the appreciable increase in torque and thrust. The readings taken at relatively shallow depths were considered more reliable than those obtained for the holes with depths greater than four times the diameter. In all tests on small drills, torque and thrust readings were taken at a depth of $^3/_8$ in., since it was found that these values could be reproduced easily at such a depth.

## Influence of Cutting Speed, Helix Angle, and Web Thickness on Torque and Thrust

*Influence of Cutting Speed on Torque and Thrust.* To determine the variations in torque and thrust as the cutting speed of a drill was changed, a drill of high-speed steel, $^3/_8$ in. diameter, was used to drill the annealed S.A.E. 1020 steel at 0.004-in. feed. The peripheral cutting speed was increased from approximately 17 to 139 fpm. The results of torque and thrust at these various speeds are shown graphically in Fig. 4; the tests were started

at the lowest speed, increased to a maximum, and then again reduced to the lowest speed as indicated by the arrows. A slight dulling effect apparently took place at the high speed, as shown by the higher curves on the return. While these curves appear to be quite similar to corresponding curves obtained when turning with single-point tools, the influence of cutting speed is negligible within the commercial range of cutting speeds, that is, above 60 fpm. This same conclusion was reached in connection with the performance of large drills (1).

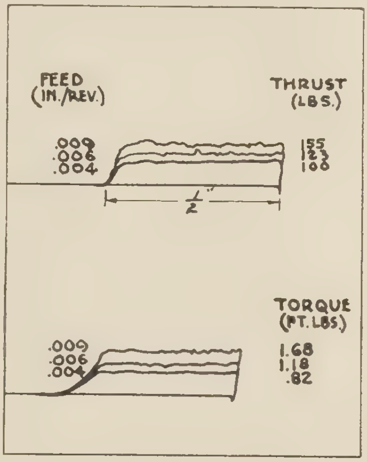


Fig. 2 Sample Torque and Thrust Chart Obtained When Drilling Free-Cutting Brass With a $^3/_8$-In. High-Speed Drill Having a 30-Deg Constant Helix Angle and a Web Thickness of 0.068 In. A 1-to-16 Emulsion Was Used With a Cutting Speed of 573 Rpm, Equivalent to 60 Fpm

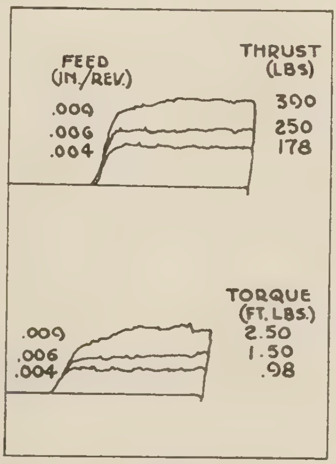


Fig. 3 Sample Torque and Thrust Chart Obtained When Drilling Annealed S.A.E. 1020 Steel With a $^3/_{16}$-In. High-Speed Drill Having a 30-Deg Constant Helix Angle and a Web Thickness of 0.035 In. A 1-to-16 Emulsion Was Used With a Cutting Speed of 1415 Rpm, Equivalent to 60 Fpm

*Influence of Helix Angle on Torque and Thrust.* A series of experiments was run with a special set of drills $^5/_{32}$ in. in diameter having web thicknesses of 0.034 in., but manufactured specially to have a wide range of helix angles. The results of the tests are shown in Fig. 5. Each test was run at three feeds of 0.004, 0.006, and 0.009 in. per revolution, respectively. It is seen that both the torque and thrust fall off gradually as the helix angle is increased, both being reduced a total of 26 per cent as the helix angle is increased from 21 deg 26 min to 40 deg 23 min. The individual points for both torque and thrust when drilling with the 0.009-in. feed are seen to be erratic, due, the authors believe,

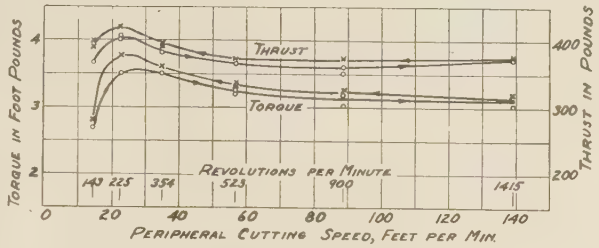


Fig. 4 Effect of Drilling Speed on Torque and Thrust When Drilling S.A.E. 1020 Steel With a $^3/_8$-In. High-Speed Drill Having a 30-Deg Constant Helix Angle and a Web Thickness of 0.068 In. A 1-to-16 Emulsion Was Used With a Feed of 0.004 In. Per Revolution

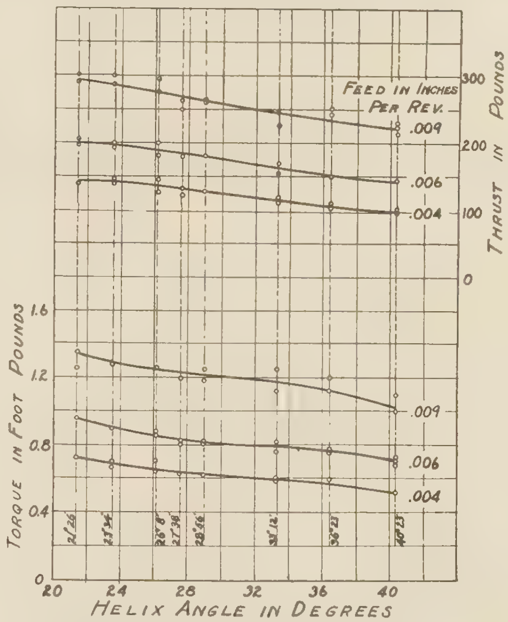


Fig. 5 Influence of Helix Angle on Torque and Thrust When Drilling S.A.E. 1020 Steel With $^5/_{32}$-In. High-Speed Drills Having a Constant Web Thickness of 0.034 In. A 1-to-16 Emulsion Was Used With a Cutting Speed of 60 Fpm

to the influence of the heavy chips in the flutes. This same tendency to reduce torque and thrust with increased helix angle has been found to hold for drills of larger diameter. The values usually reach a minimum for the largest value of helix angle, although when tool life is considered, maximum tool life is usually found to be obtained with a helix angle somewhat below the maximum shown. It is believed by the authors that an increase above 34 deg would result in lower values of torque and thrust and lower values of tool life.

The dashed line in Fig. 6 represents the torsional strength of the drill as determined by actual breaking tests in which the drills were given a thrust preload of 250 lb. This shows the greatest strength for the drills having the lowest value of helix angle. The factor of safety is greatest for the higher value of helix angle because the torque and thrust are correspondingly reduced.

*Influence of Web Thickness on Torque and Thrust.* A series

of tests was run in S.A.E. 1020 steel, with small drills of $^5/_{32}$ in. diameter having constant helix angles of 23 deg. The cutting speed was 60 fpm, and a 1-to-16 emulsion was used. The torque and thrust, recorded for the series of drills in which the web thickness was varied from 0.029 to 0.043 in., are shown graphically in Fig. 7. It is noticeable that, for the lowest feed of 0.004 in., the torque increases only slightly. For larger values of feed, a great increase in torque is noted as the web thickness is increased.

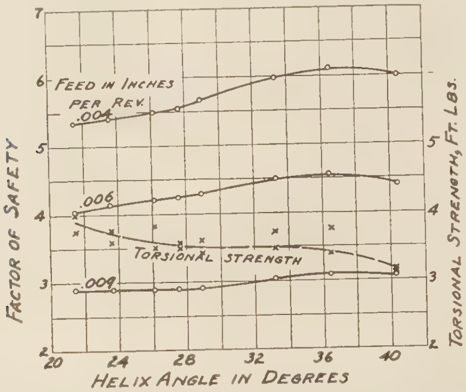


Fig. 6 Influence of Helix Angle on Torsional Strength and Factors of Safety When Drilling S.A.E. 1020 Steel With $^5/_{32}$-In. High-Speed Drills Having a Web Thickness of 0.034 In. A 1-to-16 Emulsion Was Used With a Cutting Speed of 60 Fpm

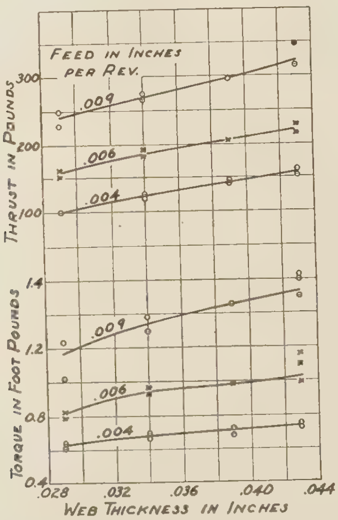


Fig. 7 Influence of Web Thickness on Torque and Thrust When Drilling S.A.E. 1020 Steel With $^5/_{32}$-In. High-Speed Drills Having a 23-Deg Helix Angle. A 1-to-16 Emulsion Was Used With a Cutting Speed of 60 Fpm

This undoubtedly is due to the fact that as the web thickness is increased the cross-sectional area of the flutes is correspondingly decreased, giving rise to a greater frictional resistance of the chips. A similar set of experiments with drills of 1 in. diameter has shown that the torque is constant for drills having different values of web thickness.

The upper three curves in Fig. 7 show the thrusts obtained for each of three feeds as the web thickness of the drill is increased. A gradual increase in thrust amounting to a total of 41 per cent is obtained as the web thickness is increased. Similar results were found in testing large drills, although for a range of comparatively narrow points, very little change in thrust was noted.

Inasmuch as there appears to be no standard proportion of web thickness to diameter in small drills manufactured by various companies, it is difficult to give a summary of true drill performance for commercial use.

The torsional strength and factor of safety of drills with variable web thicknesses are shown graphically in Fig. 8. The torsional strength of these drills appears to be about equal, giving the horizontal dashed line in Fig. 8. The torsional strength of this set of drills is seen to be lower than the variable-helix-angle drills as shown in Fig. 6. This difference is undoubtedly due to the fact that the two sets of drills were made up and heat-treated at different times. By dividing the torsional strength shown in Fig. 8 by the torque in foot-pounds shown in Fig. 7, the factor-of-safety curves shown in Fig. 8 are obtained. It is seen that the factor of safety is highest for the drills of thin web thickness.

## Torque and Thrust Values of Small Commercial Drills

Several duplicate sets of drills with unpolished flutes, ranging from $^1/_8$ in. to $^1/_2$ in. diameter having helix angles of 30 deg and ratios of web thickness to diameter equal to 0.185, were

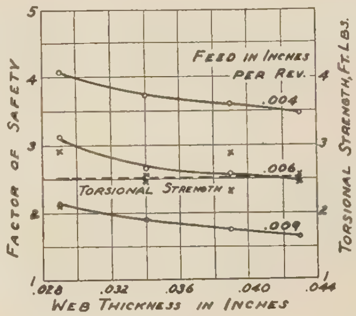


Fig. 8 Influence of Web Thickness on Factors of Safety and Torsional Strength for Conditions Given in Fig. 7

selected for use in obtaining values of torque and thrust when drilling each ferrous and nonferrous metal used in the drilling tests with large-diameter drills (3). These drills were selected to represent commercial stock, but were held to closer limits.

The 30-deg helix angle was desirable in order that the results might be compared directly with those of the larger drills used in previous tests (1, 2, 3). If small drills having helix angles less than 30 deg are used, the torque and thrust may be increased in accordance with the curves shown in Fig. 5. If different values of web thickness are used, for accurate work the torque and thrust should be corrected in accordance with the curves of Fig. 7.

All drills were machine-ground so that their form could be duplicated by successive grindings. The point angle was 120 deg, the peripheral-edge angle 130 deg, and the clearance angle at the periphery was 6 deg for drills of all diameters.

In all tests an emulsion consisting of 1 part soluble oil to 16 parts water was used. The peripheral cutting speed for each drill size was maintained at approximately 60 fpm, giving speeds of 1415, 1415, 900, 573, and 354 rpm for the $^1/_8$-in., $^3/_{16}$-in., $^1/_4$-in., $^3/_8$-in., and $^1/_2$-in. diameter straight-shank drills. In testing each metal, feeds of 0.004, 0.006, and 0.009 in. per revolution were used for each drill.

*Drilling S.A.E. 1020 Steel.* The values of torque and thrust as determined from the experiments when drilling S.A.E. 1020 steel with the several small drills each at various feeds are shown graphically on log-log paper in Fig. 9. At the lower left, plotted over the diameter of the drills, are shown the values of torque for each of the three feeds. These data are represented by the three straight lines which have a slope of 1.8 vertically to 1.0

horizontally. This slope of 1.8, therefore, represents the exponent of $d$, the drill diameter in the torque formula. This value agrees with the corresponding value previously found for large-size drills (3).

At the lower right of Fig. 9 the values of torque are plotted over the three values of feed for each of the drill diameters ranging from $^1/_8$ in. to $^1/_2$ in. These data are satisfactorily represented by the straight lines, the slope of which is 0.78. This value of 0.78 represents the exponent of $f$, the feed in the torque formula

$$T = 1740 f^{0.78} d^{1.8}$$

given in Fig. 9. The constant 1740 is obtained by substituting values for torque, feed, and drill diameter in this formula and solving for the constant. This formula agrees with the formula for torque determined on the same steel when taper-shank drills of large size were used (3). The dashed portion of the $T$-$d$ curve in which $f = 0.009$, shown in Fig. 9, represents the actual values obtained with the larger drills.

The torque in foot-pounds $T$ for the 1-in. diameter drill at 0.009-in. feed, as indicated by the point $A$ in Fig. 9, is read on the right-hand scale as 45 ft-lb. To determine the values of torque for the 1-in. drill at other values of feed, the point $A$ is projected horizontally to the point $B$ intersecting the vertical line for 0.009-in. feed. By drawing through the point $B$ the dashed line parallel to the $T$-$f$ curves shown at the lower right of Fig. 9, the torque for any other feed may be obtained graphically. Similarly, another point $A'$ on any of the $T$-$d$ lines may be projected for any drill diameter to the corresponding vertical feed line at $B'$ and another line parallel to the $T$-$f$ line drawn so that torque values for that drill size for any feed may be obtained graphically. Values of torque for drill sizes ranging from $^1/_8$ in. to $1^1/_2$ in. diameter are summarized, however, in Fig. 17, which is discussed later in the paper.

The experimental values of $B$, the thrust in pounds obtained when drilling the S.A.E. 1020 steel with the small drills, are shown in the upper part of Fig. 9. At the right, the values of thrust are plotted over the three values of feed for each of the five drill sizes. Again the points are well represented by the straight lines as indicated by a slope of 0.87. This slope represents the exponent of $f$ in the thrust formula and agrees with the data obtained for large drill sizes previously reported (3).

At the upper left of Fig. 9, the values of thrust are plotted over the drill diameter for each of the three feeds. Again the data are fairly well represented by three straight lines as indicated. The slope of these straight lines is practically 45 deg, giving a slope of 1.0 which is the exponent of $d$ in the equation. This shows the thrust to be a direct function of the drill diameter for this set of drills which has a constant ratio of web thickness to diameter. The resulting equation for thrust becomes

$$B = 104{,}300 f^{0.87} d$$

When testing the larger drills, ranging from $^1/_2$ in. to $1^1/_2$ in. diameter in which the ratio of web thickness was 0.162, 0.139, 0.141, and 0.144 for the $^1/_2$-in., $^3/_4$-in., 1-in., and $1^1/_4$-in. diameter drills, respectively, the $B$-$d$ lines on log-log paper were not straight. With the large drills, the thrust formula obtained in one set of experiments (1) was approximated as

$$B = K f^{0.78} d$$

in which the exponent 0.78 of $f$ was an average of 0.809, 0.860, and 0.681 determined under different conditions of drill diameter and feed. For an S.A.E. 1020 steel, $K = 41{,}900$.

In another set of experiments (3), involving the same nine metals used in the small-drill tests, the formula obtained considering variations in ratio of web thickness to diameter was

$$B = 785{,}000 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$$

which gives the dotted $B$-$d$ line for 0.009-in. feed shown in Fig. 9. Using this formula for thrust and the ratio of web thickness to drill diameter of 0.185 in. as maintained for the small drills, the dashed curve $B$-$d$ for a feed of 0.009 in. shown in the upper left corner of Fig. 9 is obtained. This curved line appears to be an extension of the straight line for drill diameters above approximately $^1/_2$ in. The thrust values determined by this equation are higher, however, than the actual experimental values. This indicates that, in order to fit the straight-line curve over the whole range of drill diameters from $^1/_8$ in. to $1^1/_4$ in.,

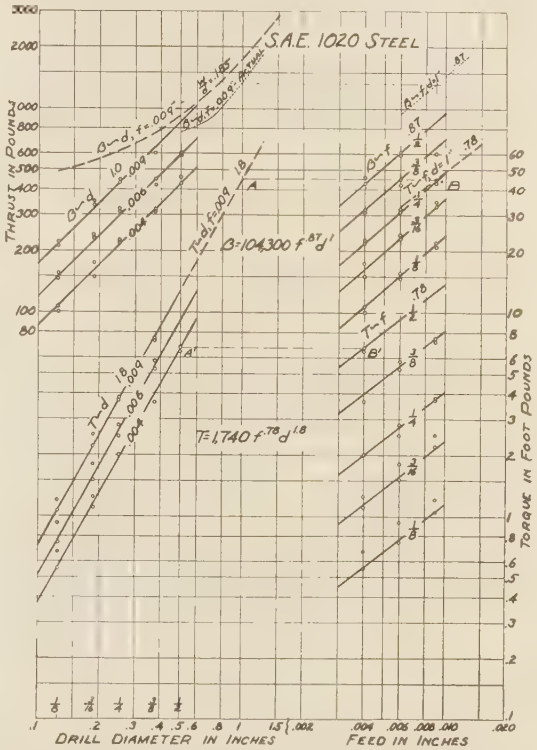


Fig. 9 Experimental Torque and Thrust Data Plotted on Log-Log Coordinates for Various Drill Sizes and Feeds When Drilling S.A.E. 1020 Steel Annealed

the ratio of web thickness to diameter should be kept constant. This does not appear to be common practice, however.

A dotted $B$-$d$ curve also is shown in the upper left corner of Fig. 9 for the large drills operating at a feed of 0.009 in. This curve is based not on a constant ratio of web thickness to drill diameter of 0.185 but on the actual ratios as given previously. It is seen that the dotted curve for drill sizes from $^1/_2$ in. to $1^1/_4$ in. is practically parallel to, but slightly lower than, the $B$-$d$ curve for the small drills operating at 0.009 in. feed. In commercial practice, whenever the web thickness is considered excessive, the drill point is thinned, reducing the ratio of web thickness to drill diameter. Values of thrust may be lowered as much as 50 per cent by point thinning.

*Drilling S.A.E. 1035 Steel.* The experimental values obtained when drilling the S.A.E. 1035 steel are plotted on log-log paper as a function of drill diameter and feed in Fig. 10. The formula for torque is

$$T = 1300 f^{0.78} d^{1.8}$$

This equation is similar to that for the S.A.E. 1020 steel, except for a lower value of the constant. In the experiments with larger drills, the value of the constant for the S.A.E. 1035 steel was found to be 1582 instead of 1300 (3). Otherwise, the equations are identical. The fact that the constant is higher in the former paper (3) may be due to the fact that the steel was furnished in duplicate bars, one being used in the tests of larger drills and the second being used in the tests of smaller drills.

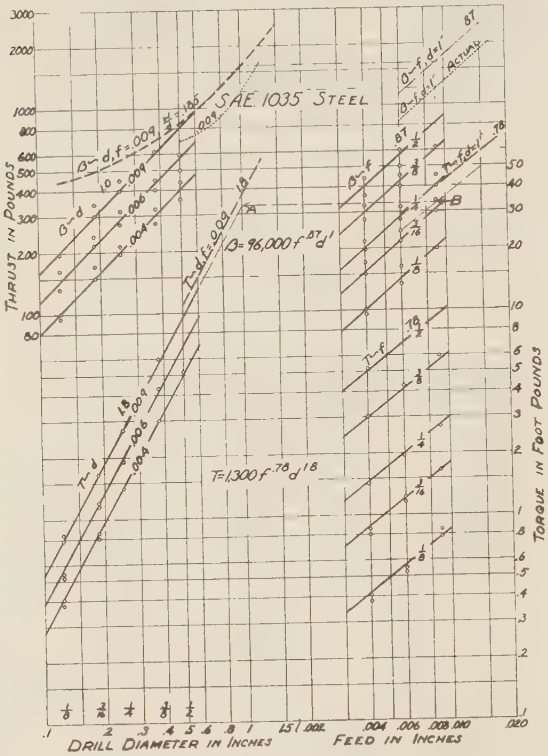


FIG. 10 EXPERIMENTAL TORQUE AND THRUST DATA PLOTTED ON LOG-LOG COORDINATES FOR VARIOUS DRILL SIZES AND FEEDS WHEN DRILLING ANNEALED S.A.E. 1035 CARBON STEEL

At the top of the $T$-$d$ curves of Fig. 10 a dashed line represents the torque as a function of diameter for the 0.009-in. feed when the large drills were used. This dashed line, if the materials were identical, would be a continuation of the solid line for 0.009-in. feed. It is higher because of the slight difference in values of the constant. By projecting point $A$ on the $T$-$d$ line for 0.009-in. feed, to the vertical line through 0.009-in. feed at $B$, the light dashed line parallel to the $T$-$f$ line is obtained. This light dashed line represents the values of torque as a function of feed for the 1-in. diameter drill as computed from the tests on small drills. The $T$-$f$ curve for a 1-in. drill, as obtained from the tests on large-size drills, is shown as a heavy dashed line just above the light dashed line. This shows the difference in values of torque for any feed in the two sets of tests.

The thrust equation is

$$B = 96{,}000 f^{0.87} d$$

as represented by the straight lines plotted as $B$-$d$ and $B$-$f$ over drill diameter and feed, respectively. The formula for thrust as obtained with the large-size drills was

$$B = 711{,}000 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$$

This equation is represented by the dotted line in the upper left corner of Fig. 10 for the 0.009-in. feed. The dashed $B$-$d$ curve for 0.009-in. feed is based on the constant ratio of web thickness to diameter of 0.185 in., and is too high for the larger drill sizes. It also shows that this formula does not hold for the small-size drills having a constant ratio of web thickness to drill diameter of 0.185.

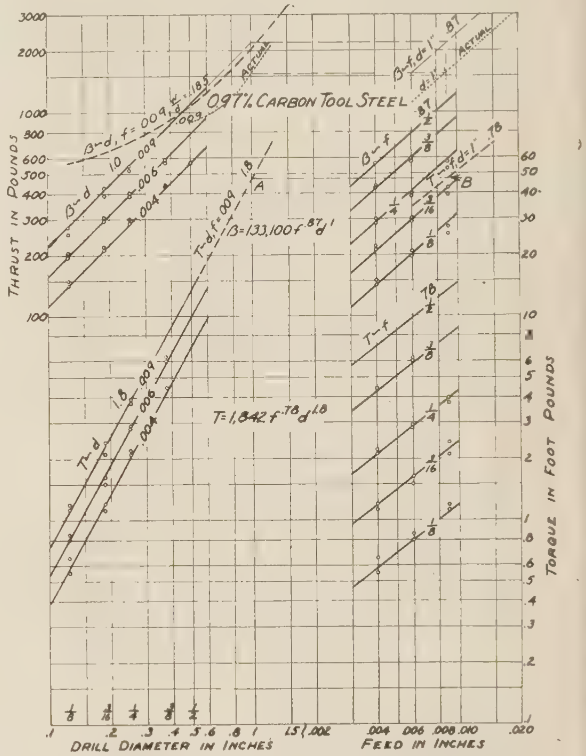


FIG. 11 EXPERIMENTAL TORQUE AND THRUST DATA PLOTTED ON LOG-LOG COORDINATES FOR VARIOUS DRILL SIZES AND FEEDS WHEN DRILLING ANNEALED 0.97 PER CENT CARBON STEEL

*Drilling 0.97 Per Cent Carbon Tool Steel.* The experimental values of torque and thrust as determined with the small drills operating in carbon tool steel are shown graphically on log-log paper in Fig. 11. The formula for torque is

$$T = 1842 f^{0.78} d^{1.8}$$

whereas the formula for the larger drills as previously determined (3) was

$$T = 1864 f^{0.78} d^{1.8}$$

The two sets of values agree closely.

For the small drills the formula for thrust as derived from the experimental data shown in Fig. 11 is

$$B = 133{,}100 f^{0.87} d$$

whereas in the experiments for larger drills with a lower ratio of web thickness to drill diameter it was

$$B = 921{,}000 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$$

The values of thrust, however, as found with the larger drills are correspondingly slightly lower than those of the smaller drills. The dashed line, showing a relation $B$-$d$, was computed using the equation for large drills but with a constant ratio of web

thickness to drill diameter of 0.185 which maintained for the small drills. The dotted *B-d* curve for the 0.009-in. feed was determined using the equation developed by the larger drills and the proper web thickness for those drills.

*Drilling S.A.E. 3150 Steel.* The experimental values of torque and thrust determined when drilling the S.A.E. 3150 steel produce lines on log-log paper quite similar to the steels previously mentioned. The formula for torque is

$$T = 1500f^{0.78}d^{1.8}$$

whereas the formula for the large drills as previously determined (3) was

$$T = 2025f^{0.78}d^{1.8}$$

The constant in the equation for small drills is somewhat lower than that in the equation for the large drills. This may be due, however, to the individual bars of material tested, inasmuch as more than one ton of this steel was purchased in one lot, and there was some slight variation from bar to bar. Also, these tests were run with drills slightly sharper than the large drills. The small-drill holes were drilled on a machined face at right angles to the scaled surface used for the large drills. These factors have been rechecked and show an influence in torque and thrust up to 12 per cent.

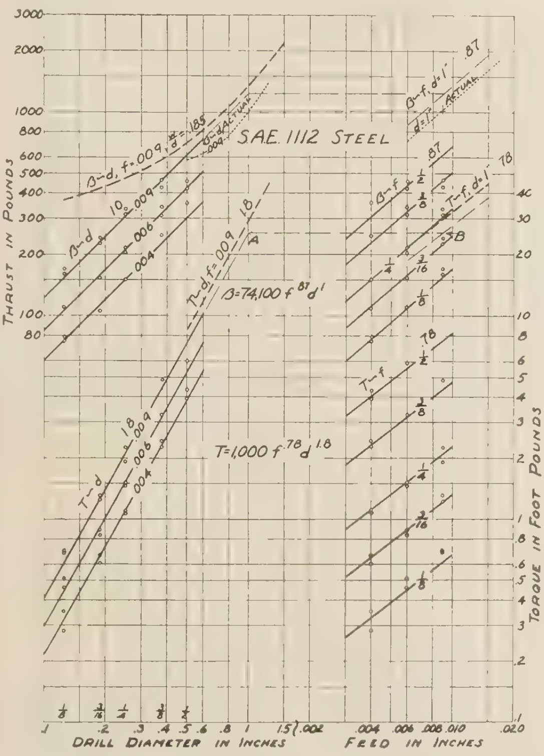


Fig. 12 Experimental Torque and Thrust Data Plotted on Log-Log Coordinates for Various Drill Sizes and Feeds When Drilling S.A.E. 1112 Steel

For the small drills the formula for thrust, as derived from experimental data, is

$$B = 108{,}500f^{0.87}d$$

whereas the experiments with large drills, having the lower ratio of web thickness to drill diameter, produced the formula

$$B = 773{,}000f^{0.87}\left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$$

The values of thrust for the large drills are slightly lower relatively than those for the small drills, as indicated by the curved lines in the summary thrust curves of Fig. 18.

*Drilling S.A.E. 1112 Steel.* The experimental data for torque and thrust as a function of drill diameter and feed when drilling the S.A.E. 1112 steel with the small drills are shown graphically in Fig. 12. The formula for torque is

$$T = 1000f^{0.78}d^{1.8}$$

The large drills gave

$$T = 1222f^{0.78}d^{1.8}$$

This indicates that the torque values for the small drills are relatively lower than those for the large drills, although the slopes of the lines are the same.

The formula for thrust for the small drills is

$$B = 74{,}100f^{0.87}d$$

whereas the corresponding formula obtained for the large drills is

$$B = 604{,}700f^{0.87}\left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$$

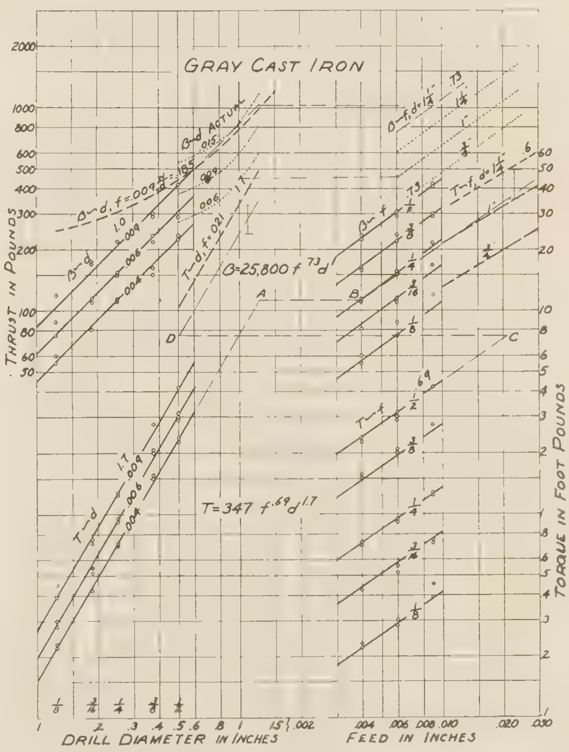


Fig. 13 Experimental Torque and Thrust Data Plotted on Log-Log Coordinates for Various Drill Sizes and Feeds When Drilling Gray Cast Iron

Again the thrust values for the large drills are slightly lower than the corresponding values obtained with the small drills. The highest dashed curve shows values of thrust computed with the formula for large drills but with the ratio of web thickness to drill diameter maintained by the small drills. This curve is too high for the whole range. The straight lines *B-d* represent the

thrust for the small drills, while the dotted line represents the actual thrust for the large drills for the 0.009-in. feed. Because of the relatively thinner webs of the large drills, the thrust values are correspondingly lower. The dotted line at the upper right of Fig. 12 represents the actual thrust for the 1-in. drill at various feeds. The dashed *B-f* line just above represents the same values obtained by projecting the results of the small drills. Values of torque and thrust also may be obtained for any condition from Tables 2 and 3 and Figs. 17 and 18.

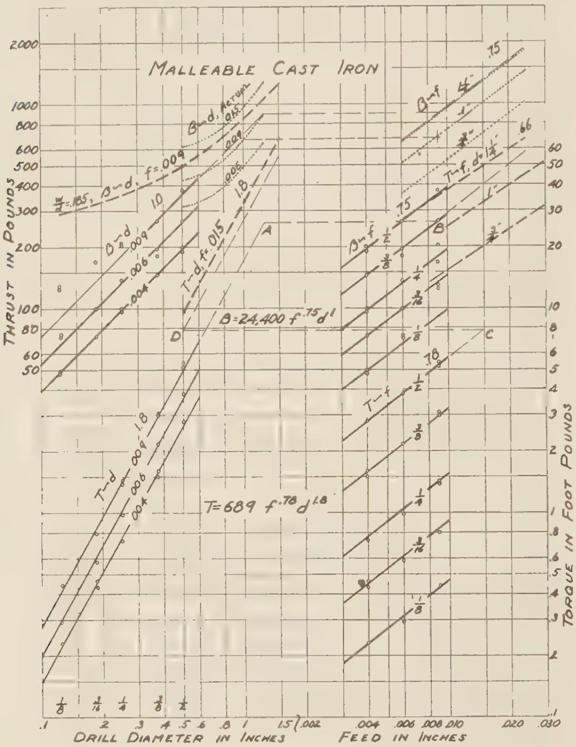


Fig. 14 Experimental Torque and Thrust Data Plotted on Log-Log Coordinates for Various Drill Sizes and Feeds When Drilling Malleable Cast Iron

*Drilling Gray Cast Iron.* Fig. 13 represents the data obtained when drilling gray cast iron. The formula for torque for the small drills is

$$T = 347f^{0.69}d^{1.7}$$

The formula obtained on this same gray iron for the large drill sizes was

$$T = 344f^{0.6}d^{1.7}$$

The constants of these two equations are practically the same, but the slope of the *T-f* lines is greater for the small drills. By projecting the point *A*, which represents the torque for the $1^1/_4$-in. drill operating at 0.004-in. feed, horizontally to the point *B* on a vertical line through the 0.004-in. feed, and drawing the dashed line through *B* parallel to the *T-f* curves, a relation is obtained between the torque and feed for a $1^1/_4$-in. drill based on the data obtained from the tests of small drills. The corresponding torque-feed line for a $1^1/_4$-in. drill, as determined with the large drills in the same gray iron, is shown slightly above by the heavy dashed line. The vertical distance at any point between these two lines represents the difference in torque obtained for this given condition at any feed. This difference is due not to a difference of the constant in the formula but rather is introduced by the difference in slope of the feed line, inasmuch as the formula for small drills shows $f^{0.69}$ whereas the formula for large drills shows $f^{0.6}$. The two lower heavy dashed lines give values of torque for the 1-in. and $^3/_4$-in. drills at any feed.

The equation for thrust obtained for the small drills is

$$B = 25{,}800f^{0.73}d$$

These values are represented graphically in Fig. 13. That obtained for the large drills in the same cast iron is

$$B = 148{,}000f^{0.73}\left(\frac{d}{5} + \frac{w}{d}\right)^{1.9}$$

The thrust values for the small drills are slightly higher relatively than those for the large drills, as represented by the *B-d* and *B-f* curves in the upper left of Fig. 13. The straight lines represent the thrust for the small drills, while the dotted lines represent the thrust for the large drills. It has been found that other values may be obtained for different types of cast iron.

From earlier experiments (1) using another gray iron, the thrust formula was

$$B = 14{,}700f^{0.6}d$$

in which the 0.6 was an average of 0.516, 0.580, and 0.710 obtained in tests with different drill sizes and feeds.

*Drilling Malleable Cast Iron.* The torque and thrust data when drilling malleable cast iron with the small set of drills are plotted in Fig. 14. The formula for torque is

$$T = 689f^{0.78}d^{1.8}$$

The formula obtained on this same malleable iron for the large drill size was

$$T = 554f^{0.66}d^{1.8}$$

The constants and exponents of the two formulas are slightly different. The heavy dashed *T-f* lines represent the values of torque for various feeds for several diameter drills. The *T-d* dashed line represents the torque for various large-diameter drills at 0.015-in. feed.

The values of torque projected from the data for small drills for the large drill size as from *A* to *B* are somewhat lower than the corresponding values obtained experimentally with the large drills. This may be due to a variation in the material used in the two series of tests or to a difference of construction of the straight-shank and taper-shank drills.

The formula for the thrust is

$$B = 24{,}400f^{0.75}d$$

The corresponding thrust formula obtained with the large drills was

$$B = 152{,}000f^{0.75}\left(\frac{d}{5} + \frac{w}{d}\right)^{1.75}$$

It is seen that the experimental values of thrust as a function of drill diameter for the greatest feed of 0.009 in. have a tendency to fall above the straight line for the lower values of drill diameter. The lower values of feed give straight lines. Aside from this one variation, the formulas for small and large drills, respectively, give values of thrust which are in close agreement. The dotted lines at the top of Fig. 14 represent the actual values of thrust obtained with the large drill sizes.

*Drilling Leaded-Brass Screw Stock.* When drilling free-cutting brass, torque and thrust values as a function of feed and drill diameter were obtained as shown graphically in Fig. 15. The formula for torque is

$$T = 512f^{0.83}d^{1.9}$$

That obtained on the same material when using the large drills was

$$T = 418f^{0.73}d^{1.9}$$

This shows relatively lower torque values for the small drills because of the larger constant and the greater feed exponent in the small-drill formula. Actual values for the small drills are shown as *T-d* and *T-f* solid lines in Fig. 15. Actual values obtained with the large drills are shown at the upper right as heavy dashed lines. The actual values for the 1-in. drill as shown by the heavy dashed *T-f* lines are higher than those of the light dashed line projected through points *A* and *B* from the 0.004-in. feed line of the small drills. This difference cannot be explained unless it is due to a lack of uniformity of the brass rod and a difference in the construction of the small- and large-size drills. The latter has been found true in check tests on the brass.

The formula for thrust obtained with the small drills is

$$B = 6160f^{0.6}d$$

while that for the large drills was

$$B = 6636f^{0.6}d$$

These two formulas are alike except for the slightly higher values of thrust obtained from the large-drill formula because of its

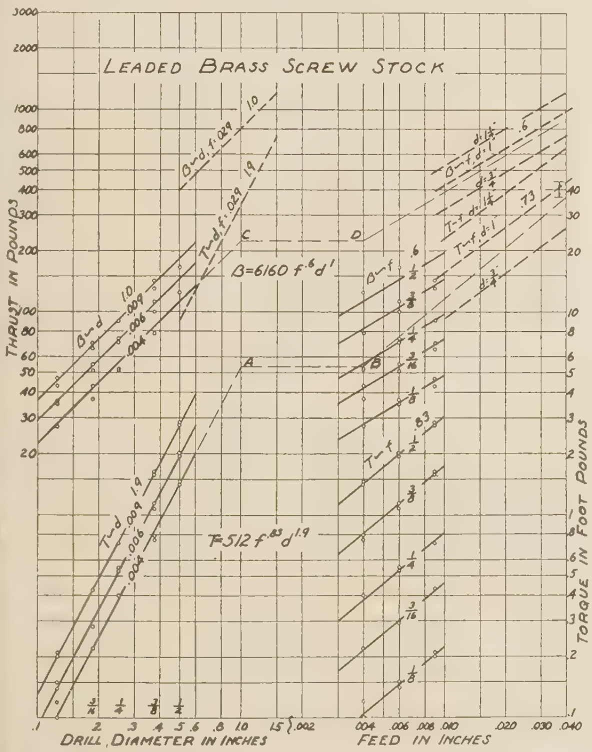


FIG. 15 EXPERIMENTAL TORQUE AND THRUST DATA PLOTTED ON LOG-LOG COORDINATES FOR VARIOUS DRILL SIZES AND FEEDS WHEN DRILLING LEADED-BRASS SCREW STOCK

larger constant. The solid *B-d* and *B-f* lines in Fig. 15 represent actual thrust values obtained with the small drills, and the dashed *B-d* and *B-f* lines indicate the thrust obtained with the large-size drills.

*Drilling Cast Aluminum Alloy S.A.E. 33.* The values of torque and thrust determined with the small drills when drilling S.A.E. 33 cast aluminum alloy are shown plotted on log-log paper in Fig. 16. The torque formula is

$$T = 556f^{0.83}d^{1.9}$$

For the large drills the torque formula was

$$T = 553f^{0.83}d^{1.9}$$

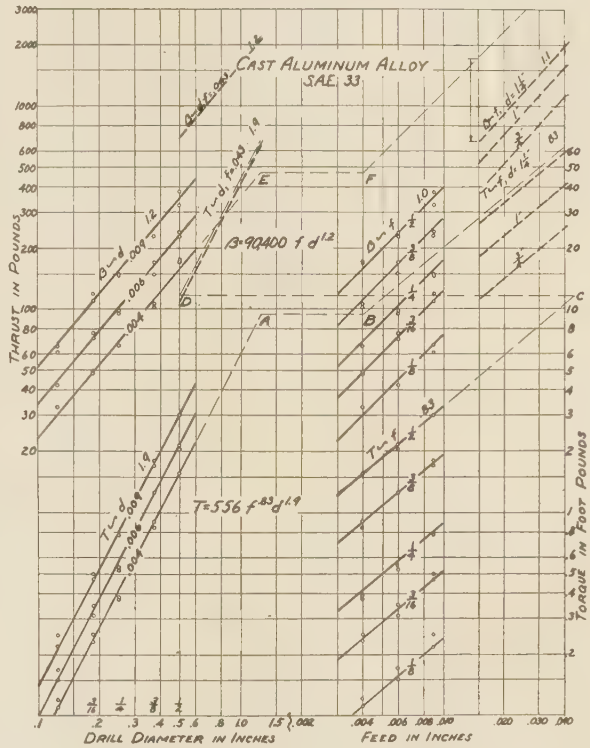


FIG. 16 EXPERIMENTAL TORQUE AND THRUST DATA PLOTTED ON LOG-LOG COORDINATES FOR VARIOUS DRILL SIZES AND FEEDS WHEN DRILLING S.A.E. 33 CAST ALUMINUM ALLOY

These two formulas agree very closely particularly in view of the fact that the formula for the large drills was obtained with $1^1/_4$-in. drills operating at feeds from 0.015 in. to 0.043 in., whereas the small drills operated at feeds from 0.004 in. to 0.009 in. By projecting the *T-d* curve for 0.004-in. feed from *A* over the $1^1/_4$-in. drill size to *B* over the 0.004-in. feed line, then drawing the dashed line through *B* parallel to the *T-f* curves, a relation is obtained for the $1^1/_4$-in. drill at various feeds. Just below the upper right end of this light dashed line are shown heavy dashed lines which represent the experimental values obtained with the heavy feeds and large drills.

The thrust equation obtained for the small drills is

$$B = 90{,}400fd^{1.2}$$

For the large drills the thrust formula was

$$B = 51{,}070f^{1.1}d^{1.2}$$

These formulas vary both in the constant and in the exponent of *f*. By projecting the *B-d* curve for the 0.004-in. feed to *E* on the $1^1/_4$-in. drill size, thence to *F* over the 0.004-in. feed line, and drawing the dashed line at the upper right parallel to the *B-f* curves, a relation is obtained between thrust and feed for the $1^1/_4$-in. drills. The heavy dashed *B-f* lines immediately below show the values obtained from the large-drill experiments.

### Recommended Values of Torque and Thrust as a Function of Drill Diameter and Feed for Steel

From the data reported for small drills in this paper and those previously reported for large drills, Figs. 17 and 18 are presented to represent graphically the values of torque and thrust, respectively, when drilling the S.A.E. 1020 steel in an annealed condition. All drills used had unpolished flutes with a helix angle of 30 deg, and ranged in size (*a*) from $^1/_8$ in. to $^3/_8$ in. and (*b*) from $^3/_4$ in. to $1^1/_4$ in. The ratio of web thickness to drill diameter for the $^1/_8$-in. to $^3/_8$-in. size range was 0.185 while for the $^3/_4$-in. to $1^1/_4$-in. size range the ratio was 0.14.

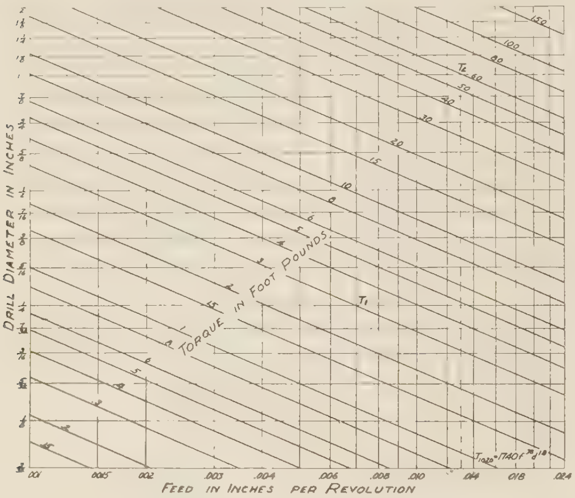


Fig. 17 A Chart on Log-Log Coordinates Showing the Relation Between Drill Diameter, Feed, and Torque When Drilling Annealed S.A.E. 1020 Steel, With Commericial High-Speed 30-Deg Helix Drills at 60 Fpm and Using a 1-to-16 Emulsion. The Web Thickness Is Given in Fig. 18

*Torque for S.A.E. 1020 Steel.* For the S.A.E. 1020 steel the value of $C$ in the torque equation for the small-size drills was found to be 1740, and for the large drills 1758. This small difference may be accounted for in the difference in cutting fluid used in the two sets of tests, the degree of sharpness and the grinding of the drills. The small drills were ground with a cylindrical surface back of the cutting edge to provide the clearance. The large drills, ground on another machine, had a conical surface formed back of the cutting edge.

From Fig. 17 it is seen that the value of torque for a $^1/_4$-in. drill operating at 0.007-in. feed in the S.A.E. 1020 steel using an emulsion of one part soluble oil to sixteen parts water is 3 ft-lb at $T_1$ the intersection of the horizontal line through $^1/_4$-in. drill size and a vertical line through the 0.007-in. feed. Similarly, $T_2$ represents 60 ft-lb, the torque developed by a 1-in. drill operating at 0.013-in. feed under the same conditions.

*Torque for Other Steels.* The torque for several other steels may be obtained from Fig. 17 using factors given in Table 2. Table 2 summarizes the formulas for torque, the values of the constant in the equation, and the factors for both small and large drills by which the torque values determined for the S.A.E. 1020 steel in Fig. 17 may be multiplied to obtain the torque when drilling the several steels listed. To illustrate, the torque required to drill S.A.E. 1035 steel with a 1-in. drill at 0.013-in. feed is determined from Fig. 17 and Table 2. The 60

TABLE 2 TORQUE FACTORS FOR SMALL AND LARGE DRILLS OPERATING IN STEELS WITH A 1-TO-16 EMULSION

| Steel | Small drills — $^1/_8$ to $^1/_2$ in. diameter — Formula | Factor | Large drills — $^1/_2$ to $1^1/_2$ in. diameter — Formula | Factor |
|---|---|---|---|---|
| S.A.E. 1020 | $T = 1740 f^{0.78} d^{1.8}$ | 1.00 | $T = 1758 f^{0.78} d^{1.8}$ | 1.00 |
| S.A.E. 1035 | $T = 1300 f^{0.78} d^{1.8}$ | 0.75 | $T = 1582 f^{0.78} d^{1.8}$ | 0.90 |
| 0.97% C tool steel | $T = 1842 f^{0.78} d^{1.8}$ | 1.06 | $T = 1864 f^{0.78} d^{1.8}$ | 1.06 |
| S.A.E. 3150 | $T = 1500 f^{0.78} d^{1.8}$ | 0.86 | $T = 2025 f^{0.78} d^{1.8}$ | 1.15 |
| S.A.E. 1112 | $T = 1000 f^{0.78} d^{1.8}$ | 0.58 | $T = 1222 f^{0.78} d^{1.8}$ | 0.69 |

Note: In the torque formula only the constant is changed for the different steels. The factor is the figure by which the torque, determined from Fig. 17, should be multiplied to obtain the torque for its material.

ft-lb at $T_2$ for the S.A.E. 1020 steel, should be multiplied by the factor 0.90, giving a resultant torque value of 54 ft-lb for the S.A.E. 1035 steel.

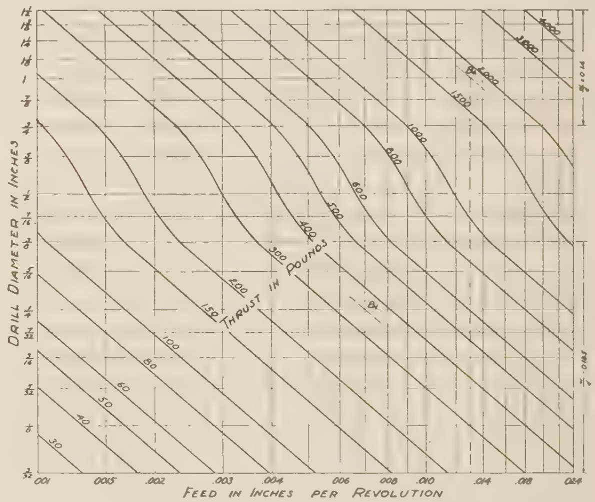


Fig. 18 A Chart on Log-Log Coordinates Showing the Relation Between Drill Diameter, Feed, and Thrust When Drilling Annealed S.A.E. 1020 Steel With Commercial High-Speed 30-Deg Helix Drills at 60 Fpm Using a 1-to-16 Emulsion. The Ratio of Web Thickness to Drill Diameter Was 0.185 for Drills up to $^3/_8$ In., but Was 0.162 for the $^1/_2$-In. Drill and 0.14 for the $^3/_4$-In. and Larger Drills

*Thrust for the S.A.E. 1020 Steel.* Average commercial values of thrust as a function of drill diameter and feed are shown graphically in Fig. 18 for drills with unthinned points drilling S.A.E. 1020 steel with a 1-to-16 emulsion. A ratio of web thickness to drill diameter of 0.185 was used for the drills up to $^3/_8$ in. diameter and a ratio of 0.14 was used for the drills from $^3/_4$ in. to $1^1/_4$ in. diameter. One formula was derived for small-diameter drills and another for the large-diameter drills. The

TABLE 3 THRUST IN POUNDS FOR SMALL AND LARGE DRILLS OPERATING IN STEELS WITH A 1-TO-16 EMULSION

| Steel | Small drills — $^1/_8$ to $^1/_2$ in. diameter — Formula | Factor | Large drills — $^1/_2$ to $1^1/_2$ in. diameter — Formula | Factor |
|---|---|---|---|---|
| S.A.E. 1020 | $B = 104300 f^{0.87} d$ | 1.00 | $B = 785000 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$ | 1.00 |
| S.A.E. 1035 | $B = 96000 f^{0.87} d$ | 0.96 | $B = 711000 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$ | 0.91 |
| 0.97 % C tool steel | $B = 133100 f^{0.87} d$ | 1.27 | $B = 921000 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$ | 1.18 |
| S.A.E. 3150 | $B = 108500 f^{0.87} d$ | 1.04 | $B = 773000 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$ | 1.00 |
| S.A.E. 1112 | $B = 74100 f^{0.87} d$ | 0.71 | $B = 604700 f^{0.87} \left(\frac{d}{5} + \frac{w}{d}\right)^{2.12}$ | 0.77 |

Note: As the constant changes, the thrust for any steel may be obtained by determining for each range of drill size the thrust for the drill size and feed in Fig. 18 and multiplying by its factor.

curves of constant thrust for the drills between 3/8 in., and 3/4 in. diameter are gradually merged because of the change in ratio of web thickness to diameter of the drills within this range.

When drilling S.A.E. 1020 annealed steel with a 1/4-in. drill at 0.007-in. feed, a thrust value of 350 lb is obtained at the point $B_1$ in Fig. 18. Similarly, at $B_2$ is indicated a thrust value of 1850 lb for the 1-in. drill operating at 0.013-in. feed.

*Thrust for Other Steels.* Table 3 has been prepared to summarize the thrust formulas and to give the constants for both small-size and large-size drills operating in various steels. To determine the thrust when drilling S.A.E. 1035 steel with a 1-in. drill at 0.013-in. feed, the thrust, as shown at $B_2$ of Fig. 18, for S.A.E. 1020 steel, is multiplied by the factor 0.91 given in Table 3 for the large drills operating in the S.A.E. 1035 steel. This gives 1680 lb.

## Conclusions

While the conclusions developed experimentally have been presented for the several cases in the figures described in this paper, attention might be called to the changes made possible through the introduction of any variable, such as a slight difference in analysis or heat-treatment of the metal, the type and condition of the drills, and the exact nature of the cutting fluids. The cutting fluid itself may account for an appreciable difference in values between the small-drill and the large-drill series of tests. An emulsion of 1 part soluble oil to 16 parts water was used in the small-drill tests, while an emulsion of 1-to-10 was used in the large-drill tests.

The materials used in the small-drill tests were purchased and used in the large-drill tests a matter of two or three years ago and some variation exists between the various bars of the given type of material. It also appears that there is fundamentally a difference in performance between the small straight-shank drills and the larger taper-shank drills. This in itself is a suggested subject for further investigation.

While the formula for torque obtained when drilling each metal with small and large drills is substantially the same, there is a slight difference in some instances in the constant of the equation. The development of a universal formula for thrust appears to be more difficult. In the early tests on a large number of steels (1), formulas were obtained similar to those obtained in the present tests with small drills. The exponents of the equation, as well as the constant, were slightly different, however, due largely to the characteristics of the steels.

The graphs prepared for the steels, together with Figs. 17 and 18, will furnish values for torque and thrust for the whole range of drills for those steels tested. The graphs for the cast irons, brass, and aluminum have been made as complete as possible so that information for all drill sizes can be read directly from them. These various graphs are congested to make the paper as condensed as possible.

## Acknowledgments

The work on small drills was taken from the dissertation of Dr. Gilbert which represented the partial requirement for his degree of Doctor of Science. The authors wish to acknowledge the assistance of C. J. Oxford, of the National Twist Drill and Tool Company, who furnished the drills used in the tests, and offered many valuable suggestions. The authors are indebted to J. E. Andress, president of Barnes Drill Company, who furnished the drill press for testing the small drills. C. E. Kraus, of the University of Michigan, designed and constructed the small dynamometer and assisted in many ways in carrying out the work. All work was conducted in the Department of Metal Processing of the University of Michigan.

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# Long-Time Creep Tests of 18 Cr 8 Ni Steel and 0.35 Per Cent Carbon Steel[1]

By H. C. CROSS[2] and F. B. DAHLE,[3] COLUMBUS, OHIO

**This paper, submitted under the sponsorship of the Joint A.S.T.M.-A.S.M.E. Research Committee on Effect of Temperature on the Properties of Metals, is a report on long-time creep tests now in progress on water-quenched 18 per cent Cr, 9.5 per cent Ni, 0.067 per cent C steel at 1200 F, and on an annealed 0.35 per cent C steel at 850 F. Stresses used were estimated to produce rates of deformation of approximately 0.0001 per cent per hour. The tests to date have progressed from 4000 to 7000 hours.**

## Introduction

At the meeting of the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals in Atlantic City, N. J., in June, 1934, C. E. MacQuigg, chairman of subcommittee No. 3 on technical projects, was authorized to start two long-time creep tests at the Battelle Memorial Institute on the previously tested 18 Cr 8 Ni steel (K19)[4] and two long-time creep tests on a 0.35 per cent C steel to be supplied by P. E. McKinney of the Bethlehem Steel Company.

This program was undertaken to procure data for comparisons of creep rates obtained over short and long periods of time. These data will permit comparisons of values obtained by extrapolations and computations from creep tests of short lengths with the actual test data obtained over longer test periods. The tests have now run from 4000 to 7000 hours. It is planned to continue the present tests to at least 10,000 hours and they may be continued for longer periods at the discretion of the joint committee.

## Material

Specimens 15 in. long were cut from mill length B-12 of the low-carbon wrought 18 Cr 8 Ni steel (K19) and water-quenched from 2000 F. More complete data on this steel are shown in the previous report.[4]

The Brinell hardness of the heat-treated bars ranged from 149 to 152, in the same range as noted in the previous tests.[4]

The 0.35 per cent C steel was supplied fully annealed. Details of the preparation, heat-treatment, and properties of this steel are given in another report submitted by the A.S.T.M.-A.S.M.E. Joint Research Committee.[5]

## Test Equipment

The creep-test equipment at the Battelle Memorial Institute has been previously described.[4] Creep-test furnaces 15 in. long and 5 in. in diameter, which are longer, better insulated, and equipped with heavier windings than the older furnaces, were constructed for use in these tests to be more certain of dependable operation over the contemplated duration of the tests of 10,000 to 25,000 hours.

All furnaces proved to be capable on calibration of meeting fully the requirements of the A.S.T.M. tentative test method E22-

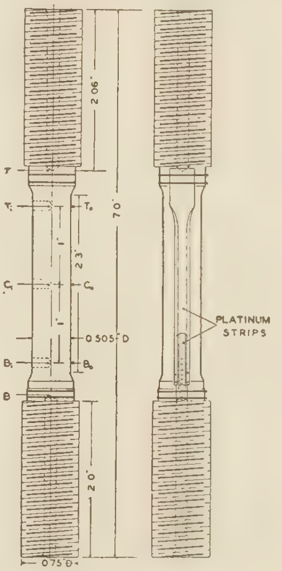


Fig. 1 Calibration and Test Specimen Used in the Long-Time Creep Tests

(Note platinum strips used for measuring deformation in the creep test.)

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[1] Progress report of the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals.

[2] Member of research staff, Battelle Memorial Institute. Upon graduation from high school Mr. Cross entered the Metallurgical Division of the Bureau of Standards. While so employed he attended George Washington University, being graduated in 1927 with the degree of B.S. in Chemical Engineering. In December, 1929, he joined the research staff of the Battelle Memorial Institute. In his work at both the Bureau of Standards and the Institute, Mr. Cross has concentrated on the investigation of the properties of metals at elevated temperatures.

[3] Assistant metallurgist, Battelle Memorial Institute. Mr. Dahle received the degree of metallurgical engineer from the School of Mines at the University of Minnesota. He was employed by the engineering department of the Great Northern Railroad for three years. Since May, 1930, he has been on the staff at Battelle specializing in research on the properties of metals at elevated temperatures.

[4] "High-Temperature Tensile, Creep and Fatigue of Cast and Wrought High- and Low-Carbon, 18 Cr 8 Ni Steel From Split Heats," by H. C. Cross, Progress Report of the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals, Trans. A.S.M.E., vol. 56, 1934, paper RP-56-6, pp. 533–553.

Contributed by the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals and presented at the Annual Meeting of The American Society of Mechanical Engineers, held in New York, N. Y., December 2 to 6, 1935.

Discussion of this paper should be addressed to the Secretary, A.S.M.E. 29 West 39th Street, New York, N. Y., and will be accepted until April 10, 1936, for publication at a later date.



[5] "Short-Time Tensile Tests at 850 F of the 0.35 Per Cent Carbon Steel Material K-20," Progress report by subgroup D on Short-Time Tensile Tests of subcommittee No. 3 on technical projects to the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals, Trans. A.S.M.E., vol. 58, 1936, paper RP-58-4, pp. 97–101.

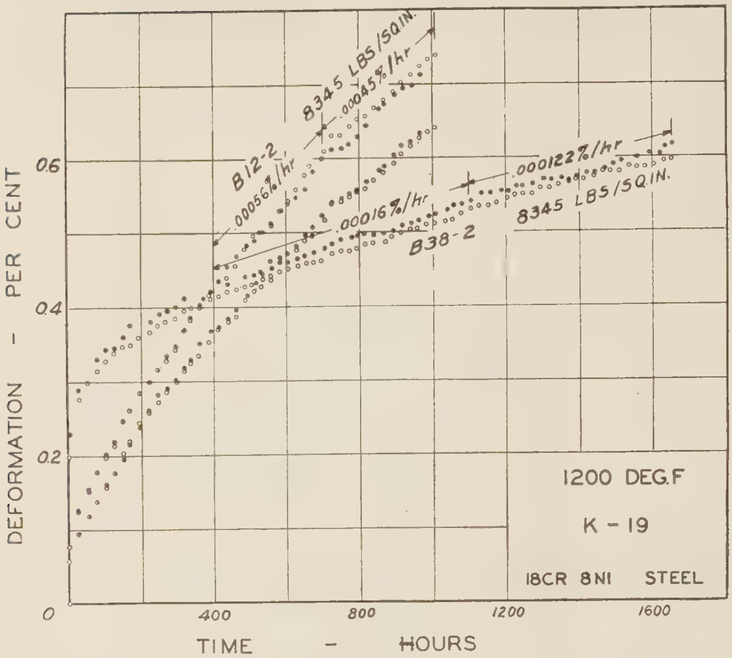


Fig. 2 Time-Deformation Curves at 1200 F for 18 Cr 8 Ni Steel (K19), Specimens B38-2 and B12-2

34T for long-time tension tests. Fig. 1 shows the test specimen used.

## Creep Tests

*Tests of 18 Cr 8 Ni Steel (K19).* As decided by the joint committee, two tests were started simultaneously on the 18 Cr 8 Ni steel (K19) at the same load as specimen B38-2 of the previous tests,[4] namely, 8345 lb per sq in. at 1200 F. These tests were on specimens B12-1 and B12-2 and were started on January 17, 1935. The time-deformation curve for specimen B12-2 is shown in Fig. 2 and the time-deformation curve for B12-1 is shown in Fig. 3. For ease of comparison the time-deformation curve for specimen B38-2 (previous test program on K-19)[4] is also shown in Fig. 2.

The initial deformations upon loading for specimens B12-1 and B12-2 were considerably less than for specimen B38-2. It soon became apparent that the rates of elongation for B12-1 and B12-2 were greater than for specimen B38-2. In Fig. 2 the curve for B12-2, although starting at a lower initial deformation, crosses the curve for B38-2 at about 500 hours and continues to show a considerably higher rate of elongation. The curve for B12-1 in Fig. 3 more nearly approximates the curve for B38-2 in Fig. 2, their total deformations at 1600 hours being 0.50 per cent for B12-1 and 0.6 per cent for B38-2. The slightly higher creep rate for B12-1 has reduced the difference between the two curves resulting from the different initial deformations.

There is a sudden increase in deformation of specimen B12-1 at 1200 hours as noted from the curve. Similar effects, but not of the same magnitude in all cases, were noted for every creep test in progress on this particular date. Careful examination of the equipment and the records of the automatic temperature recorder did not show any tangible cause for this occurrence. It was during a period of heavy rains, and since the building in the vicinity of the room containing the creep-test equipment has been gradually settling, the only explanation for this break in the creep curve is a sudden settling of the building, resulting in a decided jar to the creep-test equipment and specimens under load.

The high rate of elongation shown by specimen B12-2 was most puzzling and after consultation with C. E. MacQuigg, chairman of subcommittee No. 3 on technical projects to the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on Properties of Metals, it was decided to discontinue this test at 1000 hours and remove it for inspection and also to recheck by calibration the temperature uniformity of the creep-test furnace.

When removed, this specimen had a most unusual appearance as shown in Fig. 4. The surface was not evenly oxidized as is usually noted for 18 Cr 8 Ni steel tested at 1200 F. The spotted areas

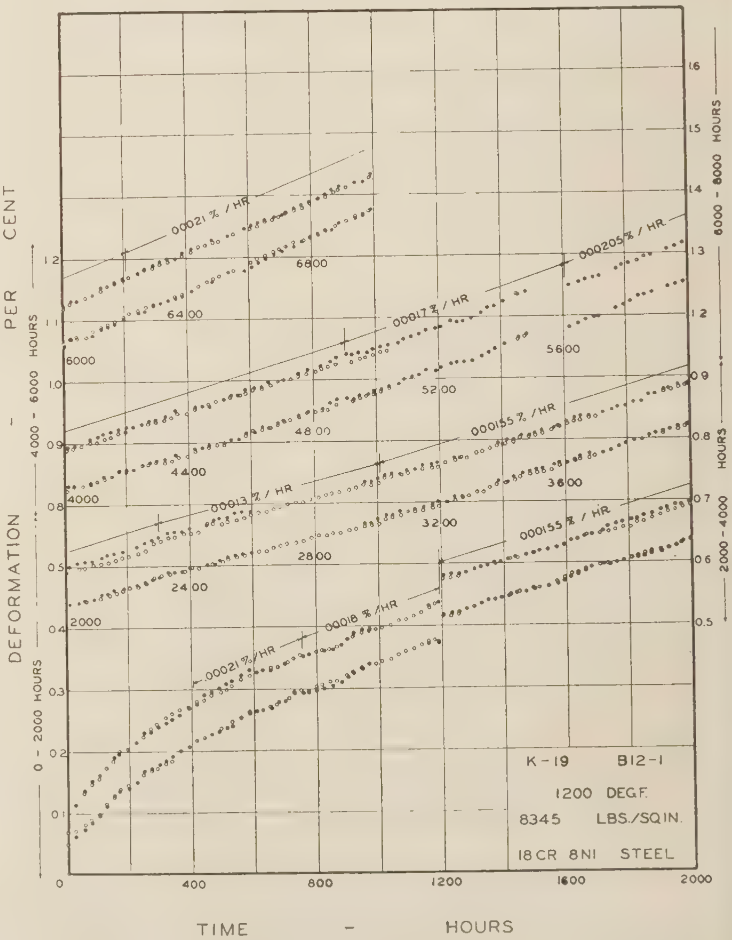


Fig. 3 Time-Deformation Curves at 1200 F for 18 Cr 8 Ni Steel (K19), Specimen B12-1

looked as if corrosion and even pitting had taken place, although the specimen was tested in a furnace with an oxidizing atmosphere but in which circulation was restricted.

Thinking that the test specimen may have been taken from a bar of improper composition requirements, the magnetic permeability was determined on this test specimen. Its permeability was even lower than specimens tested in creep and reported previously. Other 15-in. lengths from the same mill length and heat-treated at the same time as the test specimen showed equally low permeability. Recalibration of the creep-test furnace showed a variation of 2 F at one location on the test specimen. Therefore, lack of temperature uniformity apparently was not the cause of the trouble.

A disk about 0.3 in. thick was cut from the center of this test specimen. One of the large spotted areas was on this disk, which was turned over to Mr. MacQuigg for examination by Russell Franks of his company. Mr. Franks's comments after examination were as follows:

"It will be noted that the structure of this steel contains large dark spots distributed at random and in the grain boundaries. These spots appear bluish under the microscope, indicating that they represent an oxidized condition. In other words, the steel exhibited a form of intergranular oxidation which probably occurred either during manufacture or subsequently as a result of heating to moderately high temperatures for long periods. This same condition was noted in brittle 18-8 tubes we recently examined from an oil company; tubes from other oil companies have shown the same condition. The brittleness of the metal in this condition cannot be entirely eliminated by quenching from 1150 C, as in the case when the brittleness results from carbide precipitation only. The present sample also contains considerable quantities of carbide precipitated at the boundaries and inside the grains."

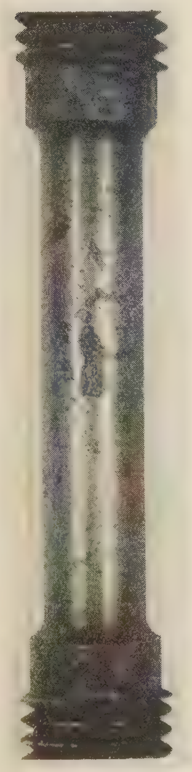

Fig. 4 Appearance of Creep-Test Specimen B12-2, 18 Cr 8 Ni Steel (K19), After Test of 1008 Hours at 1200 F, and Load of 8345 Lb per Sq In.

These data suggest the possibility of minute porosity at the points of selective oxidation or corrosion on the surface and in locations where Mr. Franks discovered an oxidized condition.

Two round Izod impact-test specimens were machined from this creep-test specimen B12-2 and when tested gave values of 103 and 104 ft-lb. The values obtained in similar impact tests on B38-2 in the previous investigation[4] were 99 ft-lb.

Another test (specimen B12-4) was started at the same load and temperature after recalibration of the creep-test furnace. This test specimen showed an initial deformation of about 0.06 per cent, which is similar to the values obtained on B12-1 and B12-2 but lower than the value for B38-2. Table 1 gives a summary of the creep-test data for the four specimens which were tested. Their time-deformation curves are shown in Figs. 2, 3, and 5.

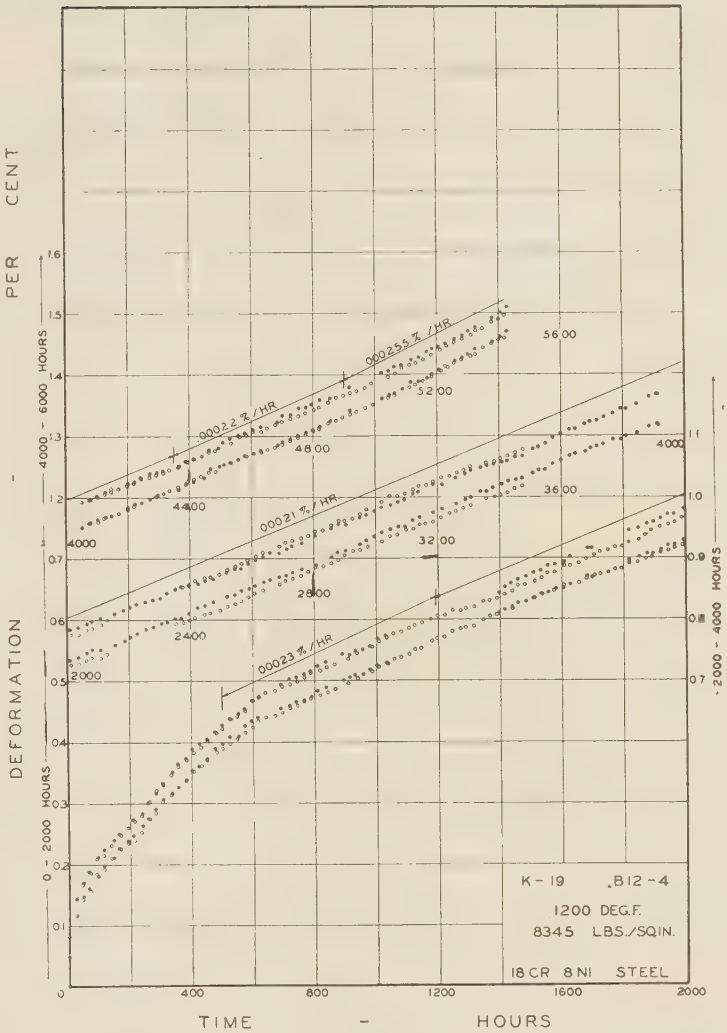


Fig. 5 Time-Deformation Curves at 1200 F for 18 Cr 8 Ni Steel (K19), Specimen B12-4

Of the two tests now in progress one test has run 7000 hours and the other has run about 5400 hours. Specimen B12-1 now at 7000 hours showed a decreasing rate of deformation up to about 3000 hours. At that time a minimum rate of deformation of 0.00013 per cent per hour was shown. As the test progressed beyond 3000 hours the rate of deformation was greater, with a noticeable increase in rate occurring at about 5800 hours and going up to a rate of 0.00021 per cent per hour at 7000 hours.

The rates of deformation at various time intervals are shown on the time-deformation curves and the values for rates of deformation and total deformations at 1000-hour intervals are shown in Table 1.

Specimen B12-4 showed an almost constant rate of deformation of 0.00021 per cent per hour from 1200 to 4500 hours. The rate

TABLE 1 CREEP-TEST DATA FOR 18 Cr 8 Ni STEEL (K19) AT A TEMPERATURE OF 1200 F AND A LOAD OF 8345 LB PER SQ IN.

| Specimen no. | B38-2 | | B12-1 | | B12-2 | | B12-4 | |
|---|---|---|---|---|---|---|---|---|
| Initial deformation, % | 0.21 | | 0.06 | | 0.07 | | 0.06 | |
| Duration of test, hr | 1655 | | 7000 | | 1008 | | 5400 | |
| | Rate of deform., per cent per hour | Total deform. per cent | Rate of deform., per cent per hour | Total deform., per cent | Rate of deform., per cent per hour | Total deform., per cent | Rate of deform., per cent per hour | Total deform., per cent |
| 500 hr | 0.000160 | 0.435 | 0.000210 | 0.27 | 0.00056 | 0.45 | 0.000430 | 0.41 |
| 1000 hr | 0.000160 | 0.510 | 0.000180 | 0.36 | 0.00045 | 0.69[a] | 0.000230 | 0.54 |
| 1600 hr | 0.000122 | 0.600 | 0.000155 | 0.50 | ..... | .. | 0.000210 | 0.67 |
| 2000 hr | ...... | ... | 0.000155 | 0.57 | ..... | .. | 0.000210 | 0.75 |
| 3000 hr | ...... | ... | 0.000130 | 0.70 | ..... | .. | 0.000210 | 0.96 |
| 4000 hr | ...... | ... | 0.000155 | 0.86 | ..... | .. | 0.000210 | 1.16 |
| 5000 hr | ...... | ... | 0.000170 | 1.01 | ..... | .. | 0.000255 | 1.45[b] |
| 6000 hr | ...... | ... | 0.000205 | 1.19 | .... | .. | ...... | .. |
| 7000 hr | ...... | ... | 0.000210 | 1.40[b] | ..... | .. | ...... | .. |
| Total computed deformation as of 10,000 hr, %[c] | 1.71 | | 2.03 | | 4.74 | | 2.648 | |

[a] Test discontinued.
[b] Test continuing.
[c] Computed by extrapolation of time-deformation curves at latest rate.

of deformation then increased, and was approximately 0.000255 per cent per hour at 5400 hours.

Specimens B12-1 and B12-4 show higher rates of deformation than specimen B38-2 tested previously[4] and discontinued at 1655 hours.

In Table 1 are shown the total deformations in 10,000 hours computed by extrapolation of the time-deformation curves. Specimen B38-2 shows 1.71 per cent deformation as compared with 2.03 per cent for B12-1 and 2.648 per cent for B12-4.

The difference of 0.32 per cent between specimens B38-2 and B12-1 is not large. Of more concern is the difference of 0.93 per cent between specimens B38-2 and B12-4, and 0.62 per cent between specimens B12-1 and B12-4. It is conceivable from the evidence that, if the test on specimen B38-2 had been continued for comparable periods of 5400 to 7000 hours, its rate of deformation would have increased above 0.000122 per cent per hour and a closer check would have resulted with the later tests now in progress.

The behavior of the two specimens run for the longer periods, is of considerable interest in that both of them, after showing diminishing rates, such as would be expected to appear as strain-hardening occurs on deformation, for periods well beyond the length of usual creep tests, then showed increasing rates as the tests progressed. The inflection in both curves occurs in the neighborhood of 3000 hours if their whole course were considered, although with specimen B12-4 the presence of the inflection was not discernible until approximately 5000 hours had elapsed.

No prediction is made as to whether the upward trend of the curves will continue, i.e., whether the third stage of creep has been permanently entered, or whether strain-hardening will again show up and the rate again diminish to give a wavy curve with the waves far apart, a phenomenon discussed by Foley.[6] Comparison of the results on the basis of accumulated strain, as brought out by Clark and Robinson[7] should also be deferred until the tests have run still longer periods.

Data for creep rates at 500 hours have been included in Tables

[6] Discussion by F. B. Foley of "An Automatic Creep-Test Furnace-Guide," by P. H. Clark and E. L. Robinson, *Metals & Alloys*, vol. 6, February, 1935, pp. 50–51.

[7] "An Automatic Creep-Test Furnace-Guide," by P. H. Clark and E. L. Robinson, *Metals & Alloys*, vol. 6, February, 1935, pp. 46–49.

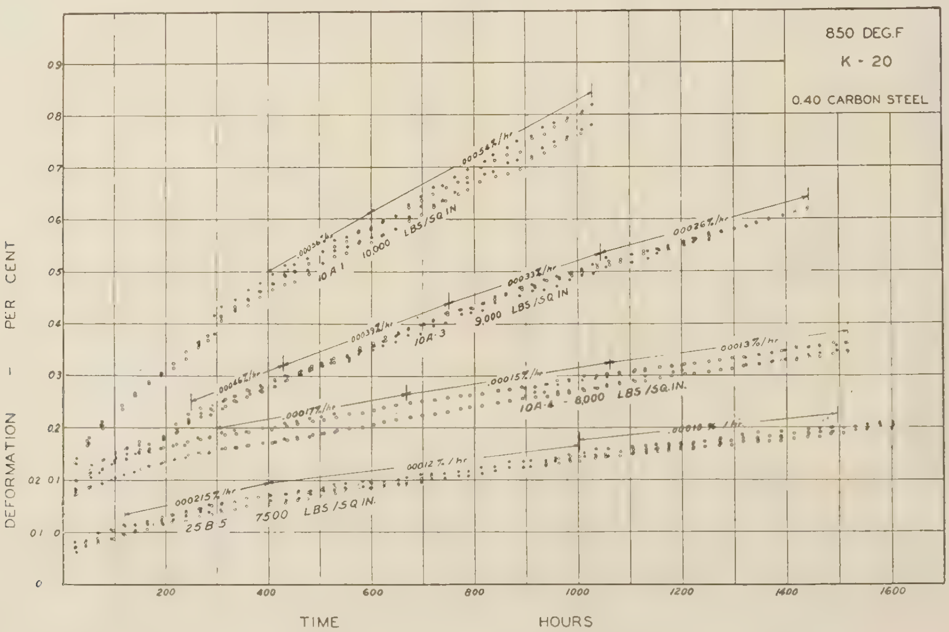


FIG. 6 TIME-DEFORMATION CURVES AT 850 F FOR 0.35 PER CENT CARBON STEEL (K20)

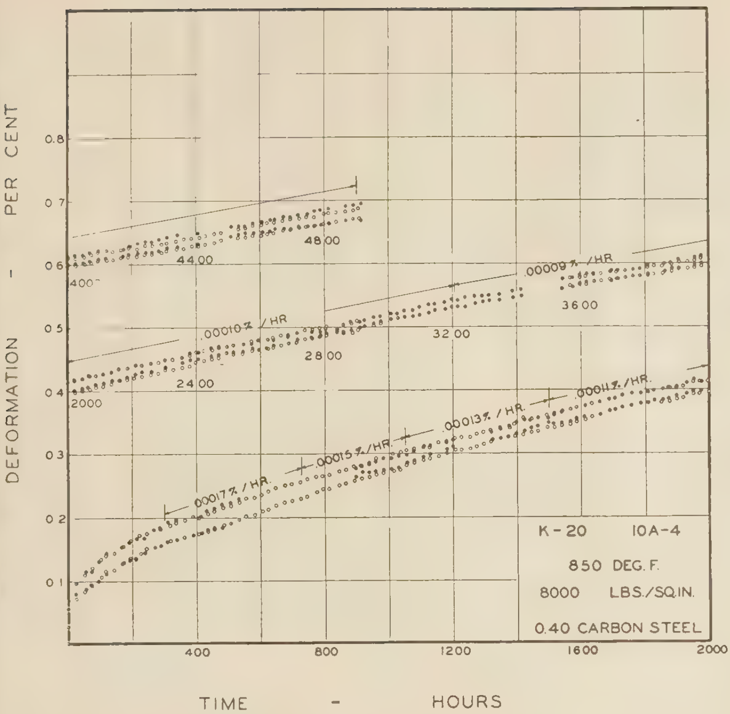


FIG. 7 TIME-DEFORMATION CURVE AT 850 F FOR 0.35 PER CENT CARBON STEEL (K20), SPECIMEN 10-A4

shown in Figs. 6, 7, and 8 and the details of the tests noted in Table 2. Considering that the hardness and tensile tests indicated a material heat-treated to produce properties probably on the soft side, the first creep test was started at 10,000 lb per sq in. This test was continued for about 1020 hours, at which time it showed a rate of about 0.00054 per cent per hour. This rate was considerably higher than desired for the long-time tests at the Battelle Memorial Institute, or the cooperative tests to be made by the different laboratories on this steel, so a second test was started at 9000 lb per sq in. This test was discontinued at approximately 1440 hours at which time it showed a deformation rate of about 0.00026 per cent per hour. This rate was also considered too high, and therefore a second test was started at 8000 lb per sq in. on a specimen numbered 10-A4, and about 850 hours later a test was started at 7500 lb per sq in. on a specimen numbered 25-B5.

At the time of the June, 1935, Detroit meeting of the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals, the test on specimen 10-A4 indicated a deformation rate of 0.00013 per cent per hour at 1580 hours and the test on specimen 25-B5 indicated a deformation rate of 0.00011 per cent per hour at 670 hours. Therefore, it was decided to continue both tests rather than run duplicated tests at the same load. These tests have been continued, and at the time this report was written the test on specimen 10-A4 at 8000 lb per sq in. had been running for 5000 hours while the test on specimen 25-B5 at 7500 lb per sq in. had been running for 4005 hours.

Specimens 10-A4 and 25-B5 have shown a steadily decreasing

1 and 2 since White, Clark, and Wilson[8] concluded that, where strain-hardening is slight, a 500-hour test may be indicative of load-carrying ability for several thousand hours, but the soundness of the indication varies with the steel. So far, a correlation with the 500-hour figure might be claimed in but one of the four long-duration tests herein reported, and that one happens to be on the 18 Cr 8 Ni steel, a notably strain-hardening material. Again, it is too early to draw conclusions.

However, these tests, together with the long-duration tests in the three references just cited,[6,7,8] strongly indicate that a whole family of creep curves, such as the one group shown by Clark and Robinson,[7] or those diagrammatically presented by McVetty,[9] will certainly be helpful, and may be necessary, for a sound engineering evaluation of creep properties. The important question, on which these tests seek to throw light, is how far do the lower-stress tests in such a family of curves need to be extended experimentally?

*Tests of 0.35 Per Cent Carbon Steel (K-20).* Some of the data available in the literature indicate that a stress of 10,000–12,000 lb per sq in. might be expected to produce 1 per cent deformation in 10,000 hours for a 0.35 per cent C steel when tested at 850 F. The time-deformation curves for the creep tests on the 0.35 per cent C steel are

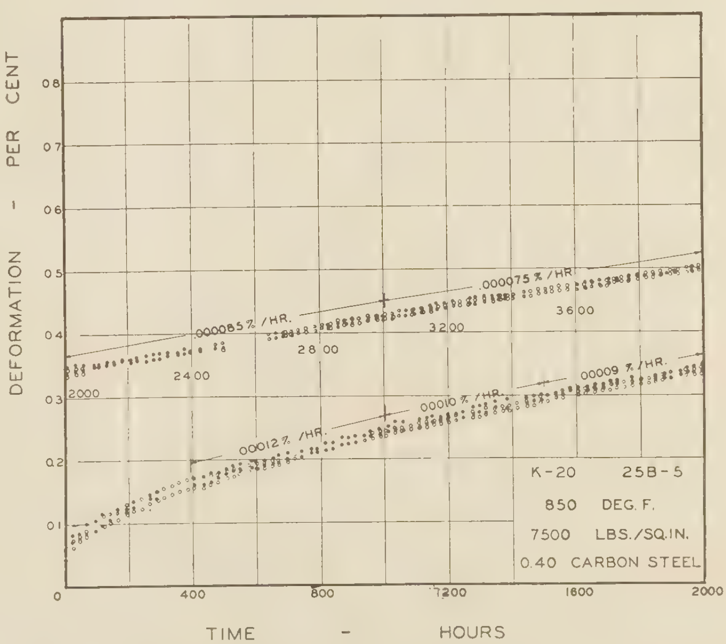


FIG. 8 TIME-DEFORMATION CURVE AT 850 F FOR 0.35 PER CENT CARBON STEEL (K20), SPECIMEN 25-B5

[8] "Influence of Time on Creep of Steels," by A. E. White, C. L. Clark, and R. L. Wilson, Proceedings A.S.T.M., vol. 35, part II, 1935, pp. 167–186.

[9] "The Interpretation of Creep Tests," by P. G. McVetty, Proc. A.S.T.M., vol. 34, part II, 1934, pp. 105–116.

TABLE 2 CREEP-TEST DATA FOR 0.35 PER CENT CARBON STEEL (K20) AT A TEST TEMPERATURE OF 850 F

| Specimen no. | 10-A1 | | 10-A3 | | 10-A4 | | 25-B5 | |
|---|---|---|---|---|---|---|---|---|
| Load, lb per sq in. | 10,000 | | 9000 | | 8000 | | 7500 | |
| Initial deformation, % | 0.05 | | 0.05 | | 0.04 | | 0.05 | |
| Duration of test, hr | 1030 | | 1440 | | 5000 | | 4005 | |
| | Rate of deform., per cent per hour | Total deform., per cent | Rate of deform., per cent per hour | Total deform., per cent | Rate of deform., per cent per hour | Total deform., per cent | Rate of deform., per cent per hour | Total deform., per cent |
| 500 hr | 0.00056 | 0.52 | 0.000390 | 0.32 | 0.00017 | 0.210 | 0.000120 | 0.175 |
| 1000 hr | 0.00054 | 0.80[a] | 0.000335 | 0.50 | 0.00015 | 0.280 | 0.000120 | 0.240 |
| 1400 hr | ..... | .. | 0.000260 | 0.60[a] | 0.00013 | 0.340 | 0.000100 | 0.280 |
| 2000 hr | ..... | .. | ...... | .. | 0.00011 | 0.400 | 0.000090 | 0.340 |
| 3000 hr | ..... | .. | ...... | .. | 0.00010 | 0.510 | 0.000090 | 0.425 |
| 4000 hr | ..... | .. | ...... | .. | 0.00009 | 0.605 | 0.000075 | 0.500[b] |
| 5000 hr | ..... | .. | ...... | .. | 0.00009 | 0.685[b] | ...... | ... |
| Total computed deformation as 10,000 hr, %[c] | 5.66 | | 2.84 | | 1.135 | | 0.95 | |

[a] Test discontinued.
[b] Test continuing.
[c] Computed by extrapolation of time-deformation curves at latest rate.

rate of deformation as the test period has increased until both are now below 0.0001 per cent per hour, with specimen 25-B5 showing a slightly lower rate of deformation than specimen 10-A4, as is shown in Figs. 7 and 8 and also in Table 2. Their computed total deformations as of 10,000 hours are 1.135 per cent for specimen 10-A4 and 0.95 per cent for specimen 25-B5.

It should be noted that it was the decision of the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals to request all those who cooperated in the long-time tests on the 0.35 per cent C steel (K20) to run their tests at least 1000 hours at a load of 7500 lb per sq in. at 850 F so that the cooperative tests may be compared with the long-time tests now in progress.

# Short-Time Tensile Tests at 850 F of the 0.35 Per Cent Carbon Steel Material K20[1]

## The K20 Material Was Tested in Accordance With the Short-Time High-Temperature Test Code, A.S.T.M. Specification E21–34T

IN ORDER to carry on a study of testing methods at elevated temperatures, the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals obtained a heat of 0.35 per cent carbon steel from the Bethlehem Steel Company. This material was designated as K20. The detailed report on the preparation and preliminary testing of this material as given by the Bethlehem Steel Company is as follows:

"In order that the various cooperating laboratories may have a complete history of the 0.35 per cent carbon steel which Bethlehem has prepared for the purpose of standardizing creep-test equipment, I am including herewith data pertinent to the melting and rolling of this particular heat.

"The melt in question was the product of a 100-ton basic open-hearth furnace. Its melting charge consisted of the following:

| | |
|---|---|
| Structural shapes | 105900 lb |
| Drop-forge flash | 13000 lb |
| Cast-iron rolls | 12400 lb |
| Hot metal (four additions) | 108700 lb |
| Total metallic | 240000 lb |

"Deoxidation was accomplished by the addition of (1) 1500 lb of 80 per cent ferro manganese in the furnace, (2) 14 per cent silicon in the furnace, and (3) 50 per cent silicon in the ladle.

"The aluminum addition consisted of 1.2 lb per ton and was added in the ladle.

"Thirty-inch corrugated ingots were used and teemed through a $1^1/_2$-in. nozzle, the following temperatures being observed during tapping and teeming: (1) Temperature while tapping, 2875 F; and (2) temperature during teeming, 2680–2660 F.

"All of the ingots (18) were moved after four hours, stripped, and charged hot into the soaking pits.

"The third ingot, from which the bars in question were taken, were heated for six hours, rolled to 4-in. by 4-in. billet stock and then ash-buried to permit slow cooling. Surface inspection revealed these billets to be entirely satisfactory from the standpoint of scale, visible defects, etc.

"Normality and acid-etch specimens taken from each end revealed fine grain (6–8) sound material and accordingly all billets were approved for rolling. It was, however, thought best to discard the bottom cut and roll 2000 lb of adjacent material to 1-in. round bar stock. This operation was conducted in the usual manner, the details of which are unimportant.

"After making carbon determinations on each of the above bars, 50 mill-length specimens were selected as representing the most uniform material chemically. These bars were numbered from one to fifty inclusive, which identity they still retain." (The carbon content of these bars is given in Table 1.)

TABLE 1 PER CENT CARBON IN BARS OBTAINED FROM BETHLEHEM STEEL COMPANY

| Bar no. | Carbon per cent, | Bar no. | Carbon, per cent |
|---|---|---|---|
| 1 | 0.35 | 26 | 0.35 |
| 2 | 0.34 | 27 | 0.36 |
| 3 | 0.34 | 28 | 0.35 |
| 4 | 0.35 | 29 | 0.35 |
| 5 | 0.36 | 30 | 0.35 |
| 6 | 0.36 | 31 | 0.36 |
| 7 | 0.35 | 32 | 0.35 |
| 8 | 0.35 | 33 | 0.36 |
| 9 | 0.34 | 34 | 0.35 |
| 10 | 0.35 | 35 | 0.36 |
| 11 | 0.35 | 36 | 0.35 |
| 12 | 0.35 | 37 | 0.36 |
| 13 | 0.35 | 38 | 0.35 |
| 14 | 0.36 | 39 | 0.36 |
| 15 | 0.36 | 40 | 0.35 |
| 16 | 0.36 | 41 | 0.36 |
| 17 | 0.36 | 42 | 0.35 |
| 18 | 0.35 | 43 | 0.35 |
| 19 | 0.35 | 44 | 0.35 |
| 20 | 0.37 | 45 | 0.36 |
| 21 | 0.36 | 46 | 0.37 |
| 22 | 0.35 | 47 | 0.35 |
| 23 | 0.36 | 48 | 0.35 |
| 24 | 0.35 | 49 | 0.35 |
| 25 | 0.35 | 50 | 0.36 |

"It will, therefore, be seen that the carbon content of these specimens is extremely uniform and while other elements were not checked on each bar, sufficient chemical determinations were made to convince us that the material was uniform. Complete analysis of this heat is as follows: 0.35 per cent carbon, 0.55 per cent manganese, 0.016 per cent phosphorous, 0.03 per cent sulphur, and 0.19 per cent silicon.

"Heat treatment consisted of the following operations:

"Heated to 1550 F in 2 hours, held 1 hour and furnace cooled to 1000 F from which temperature the bars were air cooled.

"Reheated to 1280 F in 4 hours, held 2 hours and cooled in the furnace to 1000 F, then air cooled.

"These treatments were conducted in the latest types of electric furnaces equipped with roller hearths and all other accessories designed to insure uniformity.

"Routine preparations of bar stock for subsequent shipment would necessarily include a cold-straightening operation which, while not entirely necessary, was inadvertently applied. In order to eliminate any cold-working effects which might have been brought about by this process all bars were again heated to 950 F and air cooled.

"Tensile tests taken from one end of each bar indicated a fair degree of uniformity while Brinell readings were very nearly identical. Upon examining the various stress-strain curves, it was thought that perhaps the slight bending encountered in straightening had not been entirely removed by the 950 F draw since an occasional variation in elastic limit was apparent.

"Accordingly, it was decided to re-treat the bars and the treating cycle was repeated with the elimination of cold straightening. Physical retests revealed a greater degree of uniformity, and after discussing the various stress-strain curves with various individuals, the bars were thought to be satisfactory for the purpose intended.

[1] Progress report by Subgroup D on Short-Time Tensile Tests, H. J. Kerr, chairman, to the Joint A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals.

Contributed by the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals and presented at the Annual Meeting of The American Society of Mechanical Engineers, held in New York, N. Y., December 2 to 6, 1935.

Discussion of the paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until April 10, 1936, for publication at a later date.

"Stress-strain curves along with Brinell hardness values for corresponding bars are submitted with this report. In calculating true elastic limit from the Baldwin-Southwark recorder curves, each vertical division on the cross-section paper is equal to 250 lb dead load, which value must, of course, be converted to pounds per square inch on a 0.505 by 2 in. specimen."

Bethlehem Steel Company
P. E. McKinney

TABLE 2 RESULTS OF IMPACT TESTS AT HIGH TEMPERATURES

| Test temperature, F | Charpy impact resistance, ft-lb: Cooperator No. 1 | | Cooperator No. 2 | |
|---|---|---|---|---|
| 80 | 31.5 | 33.5 | 32 | 33 |
| 450 | 45.0 | 45.5 | 43 | 43 |
| 600 | 44.0 | 48.5 | 40 | 41 |
| 750 | 34.5 | 35.5 | 37 | 39 |
| 850 | 28.5 | 29.0 | 32 | 32 |
| 1000 | 23.0 | 26.0 | 22 | 24 |
| 1200 | 68.0 | 73.0 | 55 | 56 |

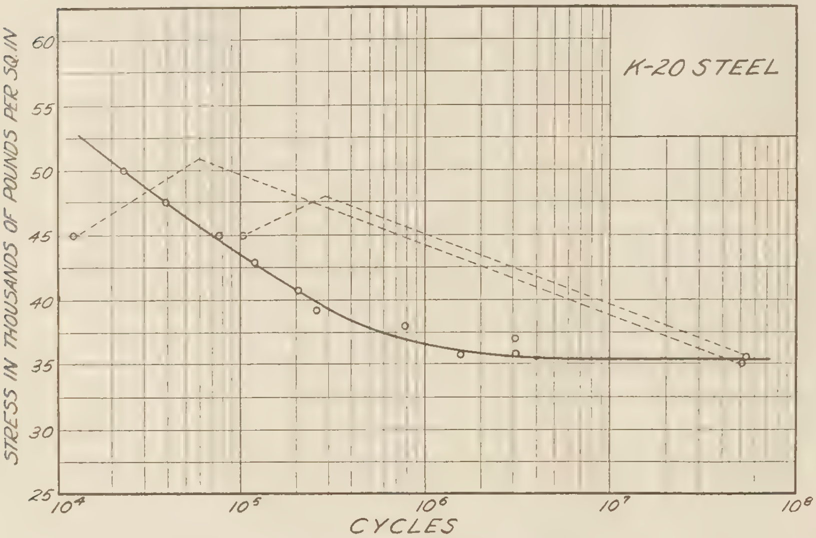


Fig. 1 Endurance Curve of 0.35 Per Cent Carbon Steel K20

Attached to Bethlehem's report were stress-strain curves representing the 49 coupons tested, and the data pertaining to their ultimate strength and ductility. The data indicate remarkable uniformity at room temperature. The minimum and maximum values, respectively, were given as: Ultimate strength, 68,000–70,000 lb per sq in.; proportional limit, 21,500–24,000 lb per sq in.; elongation in 2 in., 36.5–39 per cent; reduction of area, 62.3–65.8 per cent; and Brinell hardness number, 128–131.

A truer picture of the uniformity of the material is obtained by noting that out of the 49 tests, the ultimate strength of 39 tests showed an ultimate strength between 69,000 and 69,500 lb per sq in., 31 tests showed between 37.5 and 38.5 per cent elongation in 2 in., 47 tests showed a reduction of area between 64.7 and 65.8 per cent, and 44 tests gave a Brinell hardness number of exactly 131.

Fig. 1 shows the results of fatigue tests on the K20 steel. The tests were made on rotating-beam machines of the R. R. Moore type, giving 1740 cycles per min. The specimens were of conventional form and were polished longitudinally so as to be free from circumferential scratches.

The endurance limit at 50 million cycles is 35,500 lb per sq in. There is no indication that a value appreciably lower would be found at a still larger number of cycles. The two specimens which were unbroken after 50 million cycles were retested at 45,000 lb per sq in. The results show little evidence of strengthening by understressing, and some indication of damage by a stress of 35,000 lb per sq in.

It is generally recognized that the fatigue test is very sensitive to slight differences in the specimens and that commonly the stress-cycle relation is a band of considerable width. Steel K20 is remarkably free from this "scatter," all but two of the points being very close to a smooth curve. These tests, made at Battelle, are presented as additional evidence of exceptional uniformity of K20 material and in order still further to define its properties.

### Tests at High Temperatures

*Impact Tests.* Duplicate Charpy keyhole notch impact tests were made at seven temperatures by two cooperators. The results of the tests are given in Table 2. The specimens were held at the test temperature for $1^1/_2$ hours before testing. There is good agreement between the results submitted by the two cooperators except at 1200 F. However, the same trend of the impact-resistance curve is observed in both sets of data. These values must be regarded as short-time test results since they become entirely different after long exposure to temperature.

*Creep Tests.* Preliminary data on long-time (creep) tests of material K20 are presented in another report.[2]

### Elevated Temperature Tests at 850 F

A.S.T.M. tentative specification E21-34T was set up to provide a test code for short-time tensile tests at elevated temperatures. In order that this code might be tested, prior to its adoption as a standard, a number of members

TABLE 3 SHORT-TIME TENSILE TESTS AT 850 OF THE 0.35 PER CENT CARBON STEEL MATERIAL K20

| Co-operator No. | Ultimate strength, lb per sq in. | Proportional limit, lb per sq in. | Stress at 0.1 per cent set, lb per sq in. | Stress at 0.2 per cent set, lb per sq in. | Elong., per cent | Reduction of area, per cent | Temp at center (*Co*) of gage length, F |
|---|---|---|---|---|---|---|---|
| 1 | 51,820 | .... | .... | .... | 42.0 | 78.0 | 850 |
| | 49,180 | .... | .... | .... | 43.0 | 78.9 | 850 |
| | 49,180 | .... | .... | .... | 40.0 | 78.0 | 850 |
| 2 | 47,550 | 10,200 | 18,525 | 20,210 | 45.8 | 78.4 | 850 |
| | 49,450 | 10,100 | 18,500 | 20,200 | 45.6 | 78.3 | 850 |
| 3 | 47,700 | 18,000 | 21,000 | 23,000 | 34.0 | 77.9 | 850 |
| | 46,800 | 17,000 | 20,000 | 21,700 | 33.0 | 78.5 | 850 |
| | 46,600 | 18,500 | 21,000 | 22,500 | 34.0 | 78.7 | 850 |
| 4 | 46,350 | .... | 18,500 | 20,200 | 49.0 | 79.2 | 849 |
| | 45,700 | .... | 18,000 | 19,800 | 49.0 | 79.3 | 849 |
| 5 | 45,500 | 16,500 | 19,500 | 20,500 | 49.0 | 80.1 | 850 |
| | 45,125 | .... | .... | .... | 51.0 | 80.5 | 850 |
| 6 | 45,175 | 6,250 | 17,500 | 19,375 | 48.5 | 80.2 | 850 |
| | 44,600 | 5,000 | 16,800 | 18,750 | 48.5 | 80.4 | 850 |
| 7 | 44,200 | .... | 17,300 | 19,000 | 42.5 | 80.0 | 855 |
| | 44,800 | .... | 21,600 | 22,500 | 43.0 | 81.0 | 855 |
| | 45,100 | .... | 17,700 | 19,700 | 42.0 | 80.0 | 855 |
| 8 | 44,100 | 11,400 | 18,100 | 19,800 | 46.9 | 81.3 | 850 |
| 9 | 43,750 | 10,000 | 18,200 | 19,900 | 47.0 | 80.9 | 875 |
| | 43,400 | 11,250 | 19,100 | 20,700 | 47.5 | 80.9 | 875 |
| 10 | 40,500 | 11,000 | 18,500 | .... | 52.0 | 81.5 | 850 |
| | 46,400 | 8,000 | 17,400 | .... | 50.0 | 80.8 | 850 |
| | 42,500 | 11,000 | 17,750 | 19,750 | 56.0 | 80.6 | 850 |
| 11 | 42,800 | 15,000 | .... | .... | 49.0 | 79.8 | 850 |
| 12 | 40,200 | 10,000 | 16,500 | 18,00[illegible] | 59.4 | 84.0 | 850 |
| | 43,500 | 12,500 | 17,250 | 18,750 | 55.2 | 82.3 | 850 |
| | 43,900 | 12,500 | 18,250 | 19,500 | 53.6 | 81.8 | 850 |
| 13 | 41,500 | 10,100 | 17,600 | 18,600 | 54.4 | 82.9 | 850 |
| | 42,400 | 13,000 | 18,000 | 19,800 | 56.7 | 82.4 | 850 |

[2] "Long-Time Creep Tests of 18 Cr 8 Ni Steel and 0.35 Per Cent Carbon Steel," by H. C. Cross and F. B. Dahle, progress report of the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals, Trans. A.S.M.E., vol. 28, 1936, paper RP-58-3, pp. 91–96.

of Subcommittee D of Committee III were requested to cooperate in testing at 850 F, strictly in accordance with this code, the 0.40 per cent carbon steel known as K20.

The cooperators in this test given alphabetically are: Babcock & Wilcox Company, Battelle Memorial Institute, Carpenter Steel Company, Crane Company, Lunkenheimer Company, Midvale Steel Company, Republic Steel Company, Scovill Manufacturing Company, University of Illinois, University of Michigan, and the Westinghouse Electric and Manufacturing Company.

In preparing the various tables and charts, which are a part of this report, the cooperators have been numbered consecutively, but not in the same sequence as in the alphabetical listing.

Table 3 lists all of the data as reported by the various cooperators, as well as the temperature at the middle of the gage length on the outside of the coupon, or at point *Co*. In preparing this table, the data have been listed in the order of descending average ultimate tensile strengths.

The data from the various cooperators have been plotted in Figs. 2 and 3 in the same order. From these charts it can be seen readily that the other properties do not produce an equally smooth curve.. This is quite noticeable in the case of the proportional limit, and the elongation in 2 in. These will be discussed later under the head of "Sensitivity" and "Temperature Variation Within the Furnace."

Cooperator No. 1 did not conduct these tests according to the A.S.T.M. specification, and as a result only offered his data for comparison purposes; therefore, in making certain statements and comparisons in this report, his work has not been included.

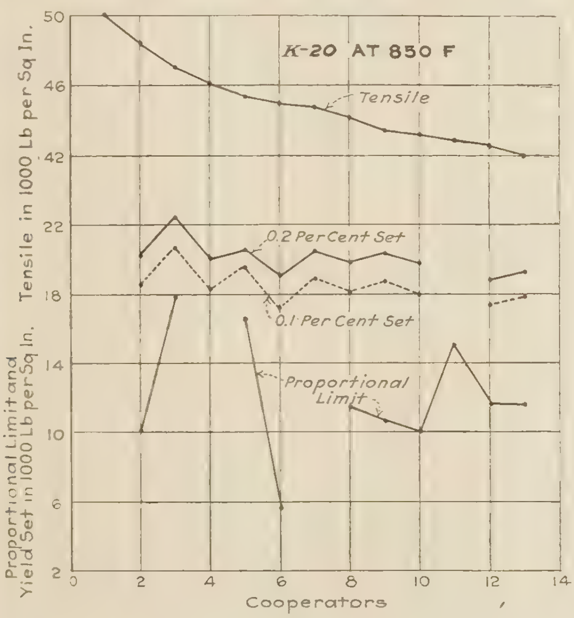


Fig. 2

The extreme variations between the highest values reported (No. 1 omitted), namely, by cooperator No. 2, and the lowest values reported, namely, by cooperator No. 13, are given in Table 4.

The factors which might enter into the variation noted between the various cooperators may be given as follows: (1) steel, (2) testing machine, (3) verification of machine, (4) room temperature, (5) temperature equilibrium, (6) calibration bar, (7) speed of testing, (8) temperature-measuring apparatus, (9) sensitivity of extensometers, (10) furnace design, and (11) variations in temperature throughout the furnace length.

TABLE 4 VARIATION OF HIGHEST AND LOWEST VALUES SUBMITTED BY COOPERATORS

| | Cooperator No. 2 | | Cooperator No. 13 | |
|---|---|---|---|---|
| Ultimate strength, lb per sq in. | 49450 | 47550 | 42400 | 41500 |
| Proportional limit, lb per sq in. | 10100 | 10200 | 13000 | 10100 |
| Stress at 0.1 per set, lb per sq in. | 18500 | 18525 | 18000 | 17600 |
| Stress at 0.2 per set, lb per sq in. | 20200 | 20210 | 19800 | 18600 |
| Elong. in 2 in., per cent | 45.6 | 45.8 | 56.7 | 54.4 |
| Red. of area, per cent | 78.3 | 78.4 | 82.4 | 82.9 |
| Temp at *Co*, F. | 850 | 850 | 850 | 850 |
| Temp at *C*, F. | 832 | 832 | 849 | 849 |
| Temp at *To*, F. | 812 | 812 | 846 | 846 |
| Temp at *Bo*, F. | 842 | 842 | 845 | 845 |

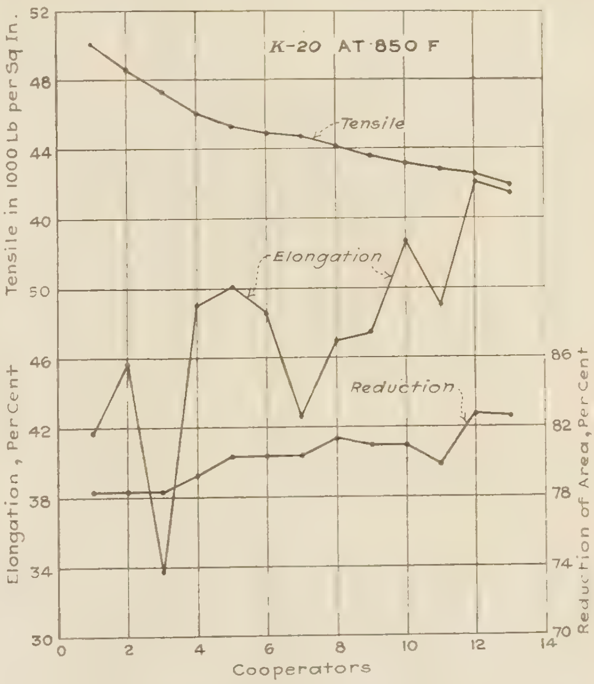


Fig. 3

*Steel.* The data submitted by the Bethlehem Steel Company and quoted earlier in this report, taken in conjunction with the uniformity as reported by other committees, warrants the elimination of the steel as a source of the variations noted between the cooperators. It is noteworthy that each cooperator obtained excellent checks on his duplicate samples, but failed in certain instances to check other laboratories by a margin that is not in keeping with the narrow range of the room-temperature tensile properties.

*Testing Machines.* All cooperators reported the use of standard machines, recently calibrated, and that the tests were made at constant room temperature, with their furnaces shielded from abnormal drafts. They also further reported at least 1 hour at temperature, so as to insure temperature equilibrium; hence these factors may be eliminated.

*Calibration Bar.* Considerable thought should be given to the question of whether a calibration bar of the type shown in Fig. 2 of A.S.T.M. specification E21-34T, indicated the actual temperatures prevailing when a standard A.S.T.M. coupon is under test. It is questionable whether the temperature distribution is the same in the two cases.

*Speed of Testing.* An effort to determine, from the data submitted, the effect of speed of testing upon the proportional limit and the 0.1 and 0.2 per cent set, disclosed that four cooperators failed to report their speeds, seven reported speed of head of machine (presumably without load), and only two reported rate of elongation between gage marks. Further, the reported speeds

TABLE 5 SENSITIVITY OF EXTENSOMETERS AND PROPORTIONAL LIMITS

| Group | Extensometer attached to | Sensitivity, in. | Proportional limit, lb per sq in. Average | Range |
|---|---|---|---|---|
| *A* | Gage length | 0.000002 | 8800 | 5000–11000 |
| *B* | Gage length | 0.000100 | 10900 | 10000–12500 |
| *C* | Shackles | 0.000100 | 11550 | 10000–13000 |
| *D* | Head | 0.000400 | 15000 | 15000 |
| *E* | Gage length | 0.001000 | 16500 | 16500 |
| *F* | Shackles | 0.001000 | 17800 | 17000–18500 |

TABLE 6

| Sensitivity, in. | Avg proportional limit lb per sq in. |
|---|---|
| 0.00002 | 8800 |
| 0.00010 | 11000 |
| 0.00040 | 15000 |
| 0.00100 | 17750 |

varied from 0.001 to 0.31 in. per min for speed of head, and from 0.00046 to 0.0065 in. per min when measured on the gage length.

Speed of testing (the rate of deformation of the specimen) appears to be a factor of importance. It is suggested that, in view of the wide differences in speed used by the cooperators, additional work be done to determine the magnitude of this factor. A closer control of speed might have corrected some of the discrepancies in the reported values. Further work might show the necessity for a more rigid specification for testing speed in the code of recommended practice.

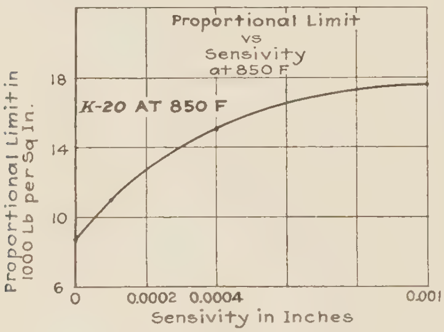


FIG. 4

*Temperature-Measuring Apparatus.* The information supplied by the cooperators warrants the conclusion that the temperature-measuring equipment was, in all cases, accurate to within at least ±2 F.

*Sensitivity of Extensometers and the Effect on Proportional Limit.* The proportional limit as determined, showed an extreme range from 5,000 to 18,500 lb per sq in. Different types, except for their sensitivity, as well as different methods of attaching the extensometers, make but little difference in the results.

Due to a difference in the method of conducting tests on duplicate bars, it was possible to divide the work of one cooperator into two groups, which were numbered cooperators No. 10 and No. 11. The real difference, in so far as this report is concerned, is the sensitivity of his extensometers. In case No. 10 he had greater sensitivity than in case No. 11.

Since the 0.1 and 0.2 per cent set results vary, as will be discussed later, in accordance with temperature conditions within the furnace, it appears that the sensitivity of the extensometer is the controlling factor in the determination of the proportional limits. The correctness of this statement is well illustrated by Table 5. The small differences between group *B* and group *C*, as well as between groups *E* and *F* warrant the data listed in Table 6 and graphically shown in Fig. 4. Therefore, if proportional limit is to be considered in this or any other specification, it must be classed in accordance with the sensitivity of the measuring device.

*Furnace Design.* This feature is so bound up with "Temperature Variations Within the Furnace Length," that they will be discussed together.

In general, it may be stated that, with one exception, the furnaces appear to be correct for the purpose intended. One cooperator is equipped with a furnace which is distinctly too short, and this condition is reflected in the results which he reported.

Two new features were reported, namely:

1 Taps from the winding are brought to the outside of the casing, thus permitting, by the use of shunts, variable control of the current through any section.

2 Suspending the furnace by cords and pulleys, with one end of a cord attached to a stationary support and the other end to the movable head of the testing machine, thus keeping the center of the coupon in the center of the furnace during the test.

Even though the furnaces appear to be correct for the purpose, a careful study of the temperature survey data indicates variations which are not only greater than allowed by specification E21-34T, but are also so great that they cause the variations noted in the test data. Table 7 is a tabulation of the temperature-survey data obtained with the calibration bar. In this table all values reported by individual cooperators were adjusted so as to bring *Co* to 850 F.

The temperature interval between the highest and lowest temperature reported at each point, by all of the cooperators in their temperature surveys is given in Table 8. The temperature interval between the highest and lowest temperature on each

TABLE 7 TEMPERATURE DATA OBTAINED FROM CALIBRATION BARS

| Cooperator No. | Point at which temperature was read *T* | *Ti* | *To* | *C* | *Co*[b] | *B* | *Bi* | *Bo* |
|---|---|---|---|---|---|---|---|---|
| 1[a] | ... | ... | ... | ... | ... | ... | ... | ... |
| 2 | ... | 788 | 812 | 832 | 850 | ... | ... | 842 |
| 3 | 846 | 850 | ... | 846 | 850 | 717 | 729 | ... |
| 4 | 849 | 852 | 849 | 850 | 850 | 850 | 853 | 848 |
| 5 | 840 | 845 | 850 | 840 | 850 | ... | 840 | 848 |
| 6 | ... | ... | 854 | ... | 850 | ... | ... | 853 |
| 7 | 815 | 818 | 833 | 845 | 850 | ... | 807 | 829 |
| 8 | ... | 817 | 846 | 842 | 850 | ... | 821 | 846 |
| 9 | 820 | 825 | ... | 835 | 850 | 810 | 820 | ... |
| 10 | ... | ... | 841 | ... | 850 | ... | ... | 841 |
| 11 | ... | ... | 848 | ... | 850 | ... | ... | 850 |
| 12 | 859 | 853 | 859 | 857 | 850 | 841 | 850 | 859 |
| 13 | 845 | 847 | 846 | 849 | 850 | 847 | 849 | 845 |

[a] No data submitted.
[b] All values reported by individual cooperators were adjusted so as to bring *Co* to 850 F.

TABLE 8 TEMPERATURE INTERVAL BETWEEN HIGHEST AND LOWEST TEMPERATURES REPORTED

| Location of temp. reading | Temperature interval, F |
|---|---|
| *T* | 44 |
| *Ti* | 65 |
| *To* | 47 |
| *C* | 25 |
| *Co* | 850[a] |
| *B* | 133 |
| *Bi* | 124 |
| *Bo* | 30 |

[a] All data submitted by individual cooperators corrected to bring *Co* to 850 F.

TABLE 9 TEMPERATURE INTERVAL BETWEEN HIGHEST AND LOWEST TEMPERATURE REPORTED ON CALIBRATION BARS

| Cooperator No. | Temperature interval on Gage length, F | Calibration bar, F |
|---|---|---|
| 1 | ... | ... |
| 2 | 62 | ... |
| 3 | 121 | 133 |
| 4 | 5 | 5 |
| 5 | 10 | 10 |
| 6 | 4 | 4 |
| 7 | 43 | 43 |
| 8 | 33 | 33 |
| 9 | 30 | 40 |
| 10 | 9 | 9 |
| 11 | 2 | 2 |
| 12 | 9 | 18 |
| 13 | 5 | 5 |

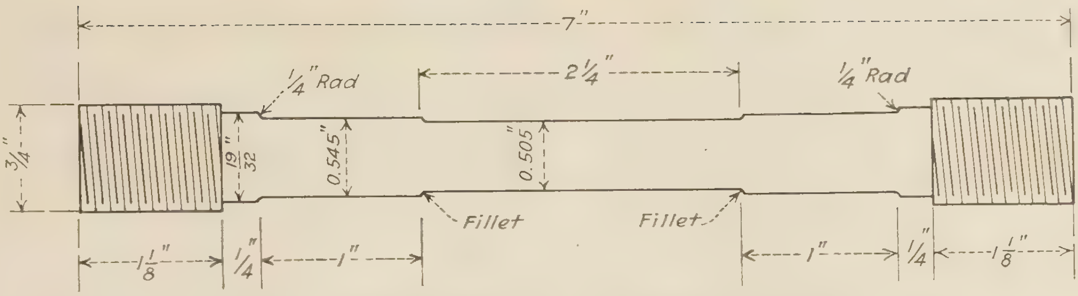


Fig. 6 Proposed Tensile Coupon for High-Temperature Tests

cooperator's calibration bar is given in Table 9. The values in the second column represent the extreme difference between any two of the points *Ti*, *To*, *C*, *Co*, *Bi*, and *Bo*, whereas the third column includes values at the additional points *T* and *B*. Only six of the 13 cooperators reported temperature variations which do not exceed the 10 deg allowed in par. 5 (*b*) of A.S.T.M. specification E21-34T.

Their data on physical properties and temperature survey, as shown by Fig. 5, is in much better agreement, but it still shows the influence of temperature variations.

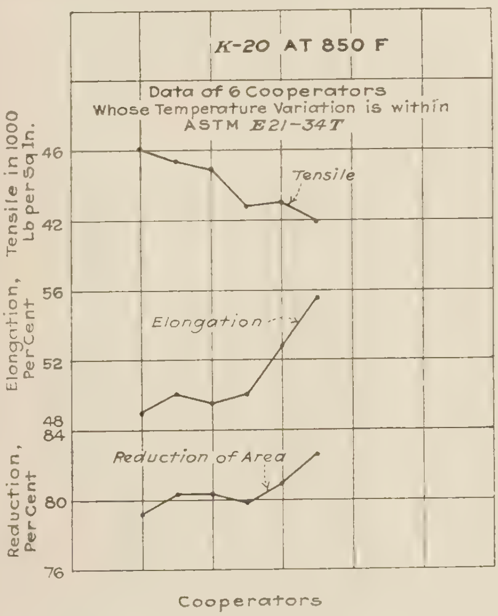


Fig. 5

One of the cooperators conducted his tests with two furnaces, having marked differences between them. These differences are reflected in his temperature surveys and physical results. In order to permit comparing these data, his work has been assigned two numbers, namely, Nos. 8 and 13.

As No. 8, he did not report temperatures at *T* and *B* and he had a difference of 33 F between *Ti*, *Bi*, and *Co* with the ends colder, hence the tensile was higher and the elongation lower than as No. 13, where the temperature between *Bi*, *Ti*, and *Co* differed only 3 F and only 5 F between any two points.

Of further interest is the fact that he used, in both cases, an extensometer of equal sensitivity, but attached it to the gage length in case No. 8 and externally in case No. 13.

A careful study of all data submitted, leads to the following conclusions:

1 Temperature differences are the principal cause of (*a*) the variations in ultimate strength, (*b*) 0.1 and 0.2 per cent set, (*c*) elongation in 2 in., and (*d*) reduction of area.

2 Sensitivity of extensometer controls the value of the proportional limit.

3 Many furnaces were not properly compensated at the ends, so as to maintain, between the gage marks, uniform and constant temperatures during the time that the coupon is under test, that is, up to the moment of fracture.

4 Insufficient heat at the ends causes the central portion of the gage length to be pulled toward a colder zone with resulting high-tensile and low-ductility values. See results of cooperators No. 3, 7, 8, and 9.

5 Overcompensation, resulting in excess heat at the ends, causes the central portion to be pulled toward a hotter zone, with resulting low tensile and high ductility. See results of cooperators No. 6 and 12.

In the opinion of Subcommittee III-D, the following changes should be made in A.S.T.M. specification E21-34T:

1 The note, under par. 5(*b*), refers to a metallic lining to bring about greater temperature uniformity. This metallic lining or other adequate means of compensation should be required.

2 Par. 5(*b*) permits a variation of 10 F in the gage length of the coupon. This should be changed to 5 F between any two points, including *T* and *B*.

3 The zone of uniform temperature should be longer, therefore the temperature survey should include points beyond the fillets and out into the threaded end of coupon.

4 Temperature to be surveyed with actual test coupons. The use of a longer coupon (see next paragraph), and a longer zone of uniform temperature will eliminate the necessity for a hollow calibration bar.

5 Coupon for elevated temperature test to be in accordance with Fig. 6.

6 Par. 6(*b*) of A.S.T.M. specification E21-34T, to be changed to require, during test, the hot junction of thermocouples at points *To*, *Co*, and *Bo*.

# High-Temperature Properties of Cast and Wrought Carbon Steels From Large Valves for High-Temperature Service[1]

By H. C. Cross[2] and F. B. Dahle,[3] Columbus, Ohio

**The authors report on a comparison made at temperatures of 750, 850, and 950 F of the short-time tension, impact, and creep properties of two forged and two cast carbon steels taken from finished valve bodies and tees obtained from the regular commercial run of three reputable manufacturers and made for service at elevated temperatures. Each manufacturer suppling the material gave it the heat-treatment normally used in his own plant for that particular type of material.**

**Two cast steels and one forged steel contained about 0.35 per cent carbon and one forged steel contained about 0.27 per cent carbon. Definite differences in structure were found. One cast steel as supplied by the manufacturer showed a spheroidized structure, while the other three steels were pearlitic.**

**Results of the creep tests are compared with the structures, and results of the short-time tension tests and impact tests at room and elevated temperatures are given.**

## Introduction

Weakness of steel in resisting deformation under long-continued loading at high temperatures is often ascribed to the grain boundaries. A corollary statement, often made without qualification, is that materials with few grain boundaries, i.e., coarse-grained ones, such as castings, are superior in creep resistance to fine-grained materials of similar composition such as rolled or forged material. This generalization is easy to remember, and the engineer is only too likely to remember it and use it without qualification.

At some high temperature, it is probably true that for a given composition and similar structure, the coarse-grained material has a higher load-carrying ability. It is not true that there is a superiority, in a coarse-grained structure, at either room temperature or at the moderately elevated temperature at which creep properties begin to be important.

The statement was perhaps originally made by French, Kahlbaum, and Peterson (1)[4] in regard to 18 Cr 8 Ni steel at 1180 F, but it was carefully qualified by comment on the dangers of coarsely crystalline metal from other viewpoints. Stanbery (2) comments on the assumption that, above the strain-hardening range, alloys of large grain size such as is found in castings are superior to those of the same composition but of smaller grain size as in the wrought state. On account of the greater likelihood of minute flaws and blowholes in castings, he balances these factors and uses the same design values for both cast and wrought materials, stating that this is the best thing to do in the present state of ignorance.

Tapsell (3) states that a higher margin of safety would be required for cast than for wrought materials in high-temperature service. One might even argue from such comments that the burden of proof as to soundness and equality of properties of cast materials as compared with wrought materials could properly be placed on the cast materials. At any rate the choice between them should be made on the basis of precise knowledge rather than vague generalities.

Workers of the present day generally qualify the statement by confining it as Stanbery did to temperatures above the equicohesive-temperature range, that is, the blue-brittle or strain-hardening range, usually without being very specific as to what the temperature is for the particular alloy under consideration.

Bull (4) states: "Other conditions being the same, a steel casting of a given composition is apt to show less deterioration from heat alone than does a steel forging or a part made of rolled steel." However, in another sentence he qualifies this as holding only at and above the blue-brittle range.

Trinks (5) states: "Experimenters are agreed that castings of a given alloy have higher creep strength than rolled or forged material of the same composition, apparently because at high temperatures the larger crystal structure resists creep or plastic flow." However, he does not specify where "high temperature" begins.

Experimental evidence for such statements rests chiefly on the results of Kanter and Spring (6), who made 500-hour creep tests on cast and wrought steels (which varied in carbon content) and later compared 0.20 per cent carbon cast and forged steels in more extended tests. At 800 F and loads approaching reasonable design loads they found no appreciable difference between the cast and wrought 0.20 per cent carbon steels, while at 1000 F and at extremely high loads a superiority of the castings was indicated. In short-time tests, even at the higher temperature, the forged steels were superior.

[1] Presented under the auspices of the A.S.T.M.-A.S.M.E., Joint Research Committee on Effect of Temperature on the Properties of Metals.

[2] Member of research staff, Battelle Memorial Institute. Upon graduation from high school Mr. Cross entered the Metallurgical Division of the Bureau of Standards. While so employed he attended George Washington University, being graduated in 1927 with the degree of B.S. in Chemical Engineering. In December, 1929, he joined the research staff of the Battelle Memorial Institute. In his work at both the Bureau of Standards and the Institute, Mr. Cross has concentrated on the investigation of the properties of metal at elevated temperatures.

[3] Assistant metallurgist, Battelle Memorial Institute. Mr. Dahle received the degree of metallurgical engineer from the School of Mines at the University of Minnesota. He was employed by the engineering department of the Great Northern Railroad for three years. Since May, 1930, he has been on the staff at Battelle specializing in research on the properties of metals at elevated temperatures.

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Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until April 10, 1936, for publication at a later date.



[4] Numbers in parentheses refer to bibliography at the end of the report.

Tapsell (3), writing just after the appearance of the paper of Kanter and Spring (6) and taking it into account, as well as his own work and that of other investigators, remarks that: "Carbon steel in the cast condition is probably no better and perhaps worse than steel which has been worked and afterward annealed or normalized."

Bailey and Roberts (7) examined a cast 0.30 per cent carbon steel and a forged 0.40 per cent carbon steel in creep at 930 F and found the forged steel to be markedly superior.

Enders (8) coarsened the grain of wrought carbon steels of 0.21 and 0.37 per cent carbon by overheating and gave varied anneals to cast carbon steels of 0.17, 0.20, and 0.33 per cent carbon. The latter two were high in manganese. These were then tested at 930 F by the accelerated method of Pomp and Enders, in which the rate of extension at some stage in a test of only 50 or 100 hours is determined and the long-time properties guessed at from this early rate. Such methods of test reflect some mixture of the short-time behavior and the beginning of the settling down to the conditions of long-time loading, and hence their results are extremely difficult to evaluate. Conclusions drawn from such tests alone are of very doubtful validity, but foreign literature is still full of them, and the conclusions become passed on and quoted as facts without qualification.

Enders concluded that the coarsened structure of the wrought steels and the as-cast, or the very coarse structure of the castings annealed so as intentionally to retain a relatively coarse structure, had greater resistance to creep at 930 F than the finer structure, although the short-time tensile values at 930 deg were but slightly affected.

White, Clark, and Wilson (9), studying the creep of wrought low-alloy steels in coarse- and fine-grained condition concluded that: "Coarse-grained steels are not enough stronger than the fine-grained steels in the important range of industrial temperatures to urge a preference for coarse-grained steels. In some respects the fine-grained steels have advantages over the coarse-grained steels."

In a report presented to this Society two years ago upon work sponsored at Battelle Memorial Institute by the Joint A.S.T.M.-A.S.M.E. Research Committee on Effect of Temperature on the Properties of Metals (10), it was brought out that, at temperatures at which the alloy is normally used for service requiring resistance to creep, cast and wrought 18 Cr 8 Ni steel of two carbon contents from two split heats failed to show any superiority in creep for the coarse-grained cast material. Indeed, the very coarse crystalline cast material tested was inferior on the whole.

The suspicion arose from this work that there might be other cases in which the generalization was inaccurate and the superiority illusory, since the coarse-grained material might show its superiority only at such a high temperature that no good engineering use could be made of it. If, through reasons of oxidation or corrosion, or through the absolute value of load-carrying ability's being so low that another type of alloy would have to be chosen for the service, a comparative superiority appearing only at an unusably high temperature would be of academic but not of engineering interest.

If it is conceded that at only slightly elevated temperature the fine-grained material is the better in creep, and at some extremely high temperature the reverse is true, the important question is: Just where do the curves cross and what are the temperature ranges in which either one shows measurable superiority? Another question is: How much of a major variable is grain size? That is, does it overbalance and swamp out other variables that may appear due to furnace practice, variations in heat-treatment, etc.? Clark (11), Kinzel (12), and Whitney (13) have each commented on extreme variations in behavior of carbon steels in creep, which they ascribe to factors other than grain size.

In view of the conflict of opinions and evidence, it appeared that it would be useful to examine plain carbon ferritic steels, cast and wrought, in somewhat the same manner that the austenitic 18 Cr 8 Ni steels had been examined at the Battelle Memorial Institute. Engineering, as well as theoretical, problems were involved, since specification-making committees of engineering societies have been faced with the problem whether to lump cast and wrought materials for high-temperature service, or to differentiate between them and require different factors of safety. The question arose in regard to valves, in particular, and in view of the conflicting evidence the permitted design loads at permitted temperatures were set the same for both materials. However, additional information bearing on the justification or lack of it for this assumed equality on an engineering basis seemed desirable. Hence, it was decided not to use a split heat but to secure commercial material in the form of actual large valves or tees, matching the chemical composition as closely as possible, consistent with suitability for a casting or a forging, rather than to penalize either the forging or the casting by choosing a composition or furnace practice suitable for one product but not necessarily acceptable to makers of the other.

To obtain test material representative of carbon steels as used in actual service at elevated temperatures, arrangements were made with several well-known valve manufacturers to supply large valves of cast and forged carbon steel taken from their regular production of such parts.

## Material

A standard 5-in. 600-lb carbon cast-steel flanged tee, designated as *C*, was obtained from one manufacturer, and a standard 5-in. 600-lb carbon cast-steel swing check valve, designated as *SC*, was obtained from another manufacturer. Complete data as to melting, casting, heat-treatment, and physical properties were furnished by each.

Chemical analyses of the two cast steels are shown in Table 1.

TABLE 1 CHEMICAL COMPOSITION OF THE CAST AND FORGED CARBON STEELS

| | Cast steel | | Forged steel | |
|---|---|---|---|---|
| Element | *C* | *SC*[a] | *F* | *LF*[b] |
| Carbon | 0.350 | 0.340 | 0.370 | 0.270 |
| Manganese | 0.630 | 0.810 | 0.610 | 0.630 |
| Phosphorus | 0.012 | 0.026 | 0.016 | 0.013 |
| Sulphur | 0.031 | 0.039 | 0.023 | 0.035 |
| Silicon | 0.340 | 0.500 | 0.240 | 0.180 |
| Chromium | 0.060 | 0.020 | 0.110 | Nil |
| Nickel | 0.170 | 0.050 | 0.180 | 0.035 |
| Tungsten | 0.000 | Nil | Nil | Nil |
| Copper | 0.19 | 0.040 | 0.040 | 0.080 |
| Molybdenum | 0.010 | 0.010 | 0.020 | 0.005 |

[a] Spheroidized.
[b] Low carbon.

The analyses of the cast steels are quite similar. The slight differences in nickel, copper, and silicon are not considered as having much effect on the properties at elevated temperatures.

With the chemical composition of the two cast carbon steels available, it was arranged with a manufacturer of forged carbon steel valves to furnish a standard 6-in. 600-lb forged tee of the same approximate chemical composition as the cast steel. Since this manufacturer usually supplies the standard 6-in. 600-lb forgings with a little lower carbon content than the content of 0.35 per cent carbon used in the cast steels, it was arranged that there be furnished also a forging from the more usual composition. The chemical compositions of the two forged steels are shown in Table 1. It will be noted that according to usual practice the two forged steels show a lower silicon content and that the forging *LF* shows a slightly lower carbon content. Otherwise, the compositions of the four steels are quite similar.

For identification purposes one cast steel has been designated as *C*, and the other cast steel designated as *SC* because metal-

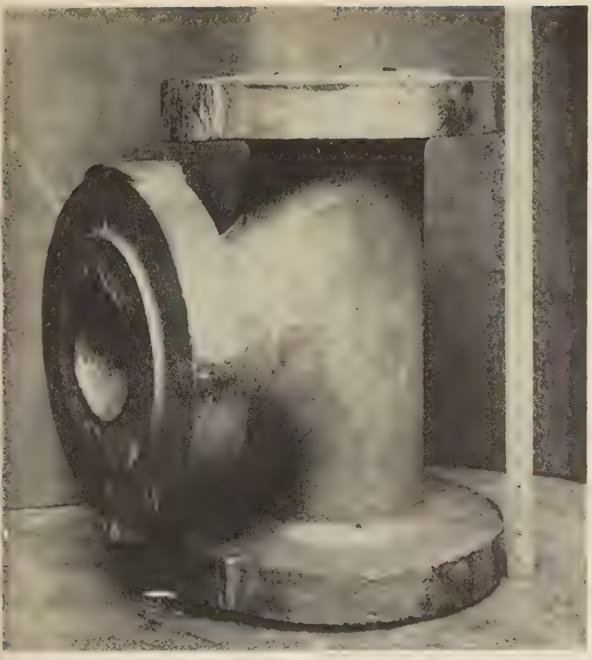


Fig. 1 Cast-Steel Tee
(Steel designated as *C*. Chemical composition given in Table 1.)

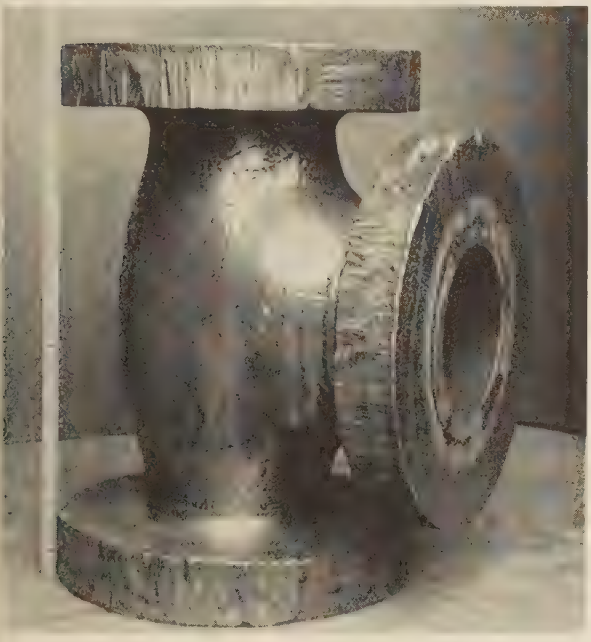


Fig. 2 Cast-Steel Valve Body
Spheroidized steel designated as *SC*. Chemical composition given in Table 1.)

ographic examination indicated it had been heat-treated to roduce a spheroidized structure. The forged steel with similar arbon content to the cast steels has been designated as *F*, and he forged steel with the lower carbon content as *LF*.

The cast-steel tee *C* was poured from a 6-ton basic electric-urnace heat, and the final deoxidation was done in the ladle with lb of aluminum per ton of steel. The casting was annealed with many others. The total annealing cycle was 19 hours. A period of 3 hours was required to reach a temperature of 1400 F and an additional hour was used to reach 1600 F, after which the temperature was held 4 hours between 1600 and 1650 F. The castings were permitted to cool in the furnace to 700 F before

Fig. 3 Forged Tees
(Steels designated as *F* and *LF*, low-carbon. Chemical composition given in Table 1.)

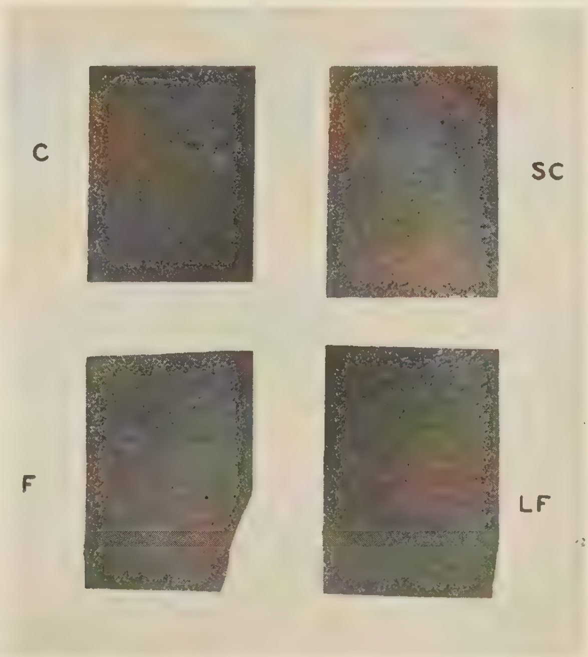



Fig. 4 Macroetched Sections of Flanges Taken From Tees and Valve Bodies of the Four Steels
(Chemical composition given in Table 1.)

being removed. Fig. 1 shows the cast tee *C*. The cast-steel valve body *SC* was poured at 2800 F. For heat-treatment the casting was heated 5 hours at 1740 F and allowed to cool slowly in the furnace, then reheated to 1440 F for two hours and cooled slowly in the furnace. Fig. 2 shows the cast-steel valve body *SC*. It was understood that these heat-treatments are standard practice with the two manufacturers.

The forged steel *F* was obtained from a heat the melting data of which were supplied as follows: Type and size of furnace, 75-ton basic open-hearth. (2) Deoxidation, 1500 lb Spiegeleisen, 800 lb of 10 per cent silicon pig, 75 lb aluminum, size of melt 187,800 lb. (3) Pouring temperature, normal. (4) Size of ingot, $22^1/_2$ in. square; Gathmann big-end-up, hot-top mold; (5) Recarbonization of melt, none. (6) Reheating and reduction of ingots, ingots not allowed to go cold. Charge placed in soaking pits for 4 hours at a temperature between 1600 F and 1900 F and then rolled at about 2100 F.

The finished forging was made from a billet about 13 in. square and 25 in. long. Forging was done in three operations, with initial break-down forging temperatures of about 2350 F, dropping to final temperatures of about 2000 F except in the final operation where all forging was carried out at 2200 F or higher.

The forged steel *LF* was obtained from a heat the melting data of which were supplied as follows: (1) Deoxidized with ferro silicon and silicon pig in the furnace. No ferro silicon was added in the ladle. Aluminum was added in the ladle at about 0.45 lb per ton. Size of melt about 100 tons. (2) Estimated pouring temperature: 2800–3000 F. (3) Heat about 12 hours. (4) Size of ingot: $22^1/_2$ in. × $22^1/_2$ in. × 72 in. Gathmann big-end-up, hot-top mold. (5) Recarbonization of heat: none. (6) Forging temperatures used were slightly lower than for the forged steel *F* with 0.37 per cent carbon.

For heat-treatment the forgings were heated to 1550 *F* for $4^1/_2$ hours and cooled in air. It is understood that the forgings supplied were taken from a number run through under this manufacturer's normal production procedure. Fig. 3 shows the type of forging supplied and designated as *F* and *LF*.

Fig. 4 shows the structure found in the flanges of the four materials used in the investigation as developed by deep etching. The sections shown were cut parallel to the radius of the flanges. Structures in steels *C* and *SC* are typical of castings. The flow lines observed in the forgings *F* and *LF* radiate from the base of the flanges.

Figs. 5, 6, 7, and 8 show the structures of the materials under test at a magnification of 100×. Fig. 5 shows the structure of cast steel *C* with large pearlite patches. Fig. 6 shows the structure of cast steel *SC* in which no pearlite patches are visible; instead the carbides are almost completely spheroidized. Fig. 7 shows the structure of the forging *F*. Smaller and more evenly distributed pearlite patches are noted when compared with cast steel *C* shown in Fig. 5. Fig. 8 shows the structure of the lower-carbon forging *LF*, in which a smaller number of well-distributed pearlite areas are noted. The two forged steels possess the smaller grain size and more uniform distribution of pearlite areas as compared with the cast steels.

Bars for preparation of test specimens were cut from end flanges and also from the bodies of the four valve bodies or tees. Every bar was subjected to X-ray examination to determine its soundness. Some slight flaws were located in bars cut from the cast steels. In the tests herein reported, such bars were discarded, and only those indicated sound by X-ray examination were used. No indications of lack of soundness were found in the bars cut from the forged steels.

### Test Specimens and Test Methods

Because of the marked effect of small errors, especially in variation of temperature from that intended, upon test results in high-temperature work, it is necessary that the methods used be stated in some detail.

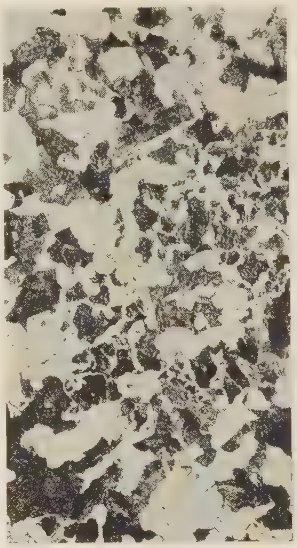


Fig. 5 Cast Steel *C* as Heat-Treated and Etched With 2 Per Cent Nital—100×

Fig. 6 Cast Steel *SC* as Heat-Treated and Etched With 2 Per Cent Nital—100×

Fig. 7 Forged Steel *F* as Heat-Treated and Etched With 2 Per Cent Nital—100×

Fig. 8 Forged Steel *LF* as Heat Treated and Etched With 2 Per Cent Nital—100×

*Short-Time Tension Tests.* The 0.505-in. diameter test specimen shown in Fig. 9 was used in the room-temperature tension tests. The yield point was determined by the drop of the beam.

For the short-time tension tests at elevated temperatures, the same type of test specimen was used in a set-up diagrammatically shown in Fig. 10. Two bars of each material were tested at each temperature; one cut from a flange and the other from the body of the valve or tee. An Amsler hydraulic testing machine of 72,000-lb capacity was used. The pulling adapters were fitted with spherical seats to assist in obtaining axial loading.

A temperature survey of the furnace according to the methods

TABLE 2 TEMPERATURE SURVEY OF SHORT-TIME TENSION-TEST FURNACE[a]

| Nominal test temperature | Top end beyond fillet $T$ | Top-gage length Inside $T_i$ | Top-gage length Outside $T_o$ | Center-gage length Inside $C_i$ | Center-gage length Outside $C_o$ | Bottom-gage length Inside $B_i$ | Bottom-gage length Outside $B_o$ | Bottom end beyond fillet $B$ |
|---|---|---|---|---|---|---|---|---|
| 750 F | 749 F | 752 F | 749 F | 748 F | 748 F | 759 F | 746 F | 744 F |
| 399 C | 398 C | 400 C | 398 C | 398 C | 398 C | 399 C | 397 C | 396 C |
| 850 F | 848 F | 851 F | 848 F | 849 F | 849 F | 852 F | 847 F | 849 F |
| 454 C | 453 C | 455 C | 453 C | 454 C | 454 C | 456 C | 453 C | 454 C |
| 950 F | 942 F | 950 F | 946 F | 951 F | 949 F | 949 F | 944 F | 933 F |
| 510 C | 506 C | 510 C | 508 C | 511 C | 509 C | 509 C | 507 C | 501 C |

[a] Position of thermocouples is indicated in Fig. 9.

recommended by the A.S.T.M. (14) is shown in Table 2. The thermocouples on the surface of the gage length were attached by spot welding.

During actual tests two thermocouples are used. The thermocouple in the bottom end beyond the fillet $B$ measures the specimen temperature, and the top couple beyond the fillet $T$ is connected to a Wilson-Maeulen automatic temperature controller.

Stress-strain curves for determination of the yield strengths were obtained by frames fastened to the adapters and fitted with two Ames dials reading to 0.0001 in. The loading was continuous, and readings of the dials were made simultaneously by two observers. After the yield point was passed, the dials were removed and the speed of the head regulated as nearly as possible to 0.25 in. per min up to the ultimate strength.

The yield strengths were obtained from the stress-strain curves as the stresses at which the materials exhibited 0.1 and 0.2 per

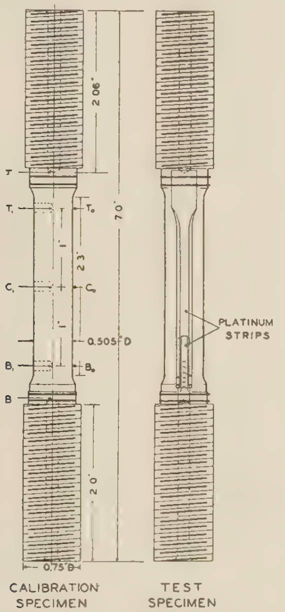



Fig. 9 Calibration and Test Specimens Used in the Short-Time Tension Tests and Long-Time Creep Tests
(Note platinum strips used for measuring deformation in the creep test.)

cent permanent set according to the Standard Methods of Tension Testing of Metallic Materials (E8-33) (15).

*Creep Tests.* The creep-test apparatus used is similar to that used by Kanter and Spring (6). Details of the creep-test equipment and a discussion of procedure and precautions taken for accuracy in creep work at Battelle Memorial Institute have been discussed elsewhere (16).

Throughout the series of creep tests herein reported the requirements of the Tentative Method of Test for Long-Time (Creep) High-Temperature Tension Tests of Metallic Materials (E22-33T) (17) have been met or exceeded.

The individual temperature-uniformity calibrations of the various creep-test furnaces are not shown, but in every case the variation of temperature over the gage length did not exceed 5 F (2.6 C), and in many instances was considerably less.

The telescope micrometer used to measure the elongations was mounted in a slide traveling on a graduated screw and was fitted with a filar micrometer eye-piece. Calibration shows its smallest division to read to 0.0000505 in., which on a specimen with approximately a 2.3-in. gage length gives readings to about 0.000022 in. per in., or 0.0022 per cent.

Readings of deformation were taken on opposite sides of the

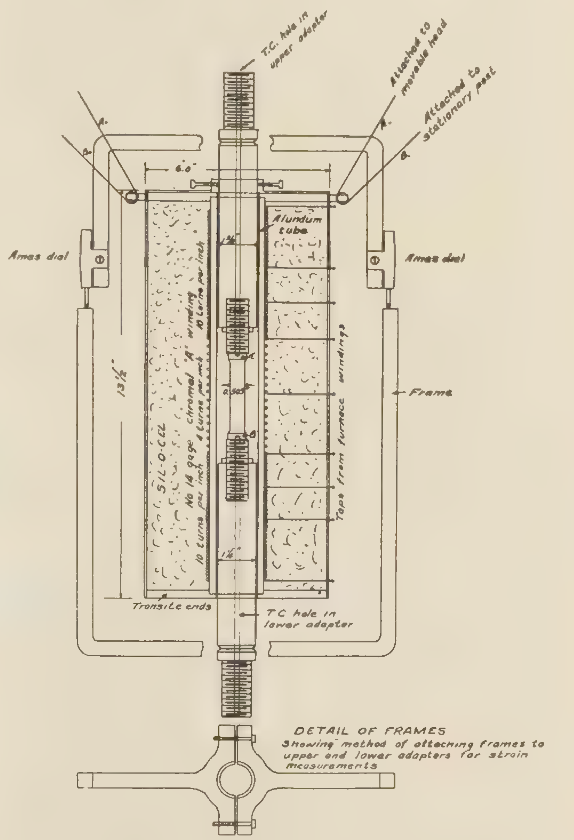



Fig. 10 Diagrammatic Set-Up for the Short-Time Tension Tests at Elevated Temperatures

test specimen. The data in this report show the time-deformation curves for the front and back of each test specimen.

After a brief initial period the rates of elongation become practically the same for both sides and the time-deformation curves parallel. After loading and throughout the test period, readings of elongation were made daily by two observers, and the time-deformation curves shown represent averages of the curves of the two observers. Either curve alone follows the average curve too closely to allow reproduction of the separate curves.

In the creep tests, specimens taken only from the flanges were tested.

*Impact Tests.* The impact tests were made on an Amsler combination Izod and Charpy impact-testing machine.

At room temperature standard Charpy keyhole-notch impact-test specimens 0.394 in. square were used. Round Izod (0.45

TABLE 3 PHYSICAL PROPERTIES OF THE MATERIALS DETERMINED AT ROOM TEMPERATURE

| Material | Yield point, lb per sq in. | Tensile strength, lb per sq in. | Elongation in 2 in., per cent | Reduction of area, per cent | Bend, deg | Brinell hardness number | Rockwell B hardness[a] | Charpy impact resistance,[b] ft-lb — Flange | Charpy impact resistance,[b] ft-lb — Body | Izod impact resistance,[c] ft-lb — Flange | Izod impact resistance,[c] ft-lb — Body |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *C* | 44700 | 78300 | 25.5 | 38.8 | 180 | 155 | 79 | 16, 14, 13 | 18, 15, 13 | 26, 26, 22 | 24, 21, 23 |
| *SC* | 45300 | 78200 | 27.8 | 43.1 | 90 | 149 | 76 | 19, 22, 15 | 13, 16, 18 | 23, 25, 26 | 23, 22, 23 |
| *F* | 45950 | 80000 | 28.2 | 39.0 | ... | 163 | 85 | 22, 19, 22 | 24, 19, 23 | 27, 32, 32 | 37, 34, 35 |
| *LF* | 37050 | 67550 | 32.0 | 52.2 | ... | 131 | 72 | 26, 23, 36 | 30, 26, 30 | 41, 55, 50 | 52, 44, 48 |

[a] Load of 100 kg on a 1/16-in. ball.
[b] Keyhole notch.
[c] Round (0.45 in. diameter) V-notch.

in. diameter—V-notch) impact test specimens (18) were also used at room temperatures for purposes of comparison with

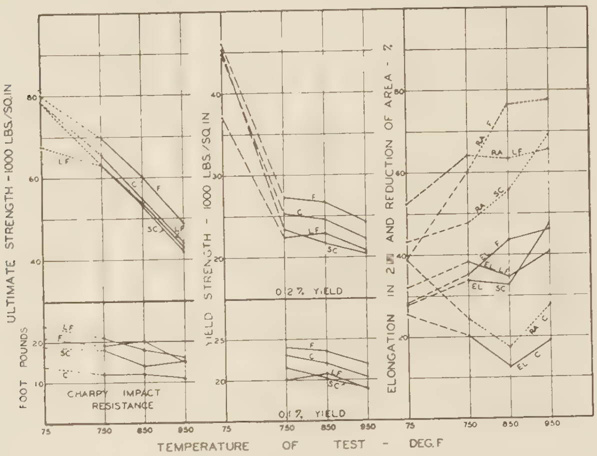



FIG. 11 RESULTS OF THE IMPACT AND SHORT-TIME TENSION TESTS AT ROOM TEMPERATURE, 750, 850, AND 950 F FOR CAST AND FORGED CARBON STEELS

($C$ = cast steel 0.35 per cent C; *SC* = spheroidized cast steel 0.34 per cent C; *F* = forged steel 0.37 per cent C; *LF* = low-carbon forged steel 0.27 per cent C.)

similar tests on specimens cut from the gage length of the creep-test specimens after removal from the creep-test equipment.

## TEST DATA

*Short-Time Tension Tests and Impact Tests.* The tension- and impact-test data obtained at room temperature for the four steels are shown in Table 3. The tension-test data on the cast steels *C* and *SC* were supplied by the manufacturers.

The values shown are averages for two bars tested.

The three steels with the higher carbon content *C*, *SC*, and *F* show tensile properties and ductility values quite similar to each other. Steel *LF* (lower carbon forging) shows a somewhat lower tensile strength and yield point and slightly higher values for elongation and reduction of area.

The tension-test data at 750, 850, and 950 F for the four steels are shown in Table 4, and the tension-test data for both room temperature and elevated temperatures are summarized in Fig. 11.

The data for tensile and yield strengths for 0.1 and 0.2 per cent permanent set place the four steels in the same relative position. The forged steel *F* shows the best properties at the elevated temperatures, with the cast steel *C* next best, and with little difference between the cast steel *SC* and the low-carbon forged steel *LF*.

The data for elongation and reduction of area show the best

TABLE 5 CHARPY IMPACT RESISTANCE OF THE MATERIALS AT ROOM TEMPERATURE, 750, 850, AND 950 F

| Steel | Resistance at 75 F, ft-lb | Resistance at 750 F, ft-lb | Resistance at 850 F, ft-lb | Resistance at 950 F, ft-lb |
|---|---|---|---|---|
| *C* | 16, 14, 13 | 11, 12, 13 | 12, 13, 12 | 12, 10, 11 |
| *SC* | 19, 22, 15 | 16, 20, 16 | 15, 11, 15 | 13, 16, 15 |
| *F* | 22, 19, 22 | 16, 25, 17 | 18, 22, 21 | 16, 16, 13 |
| *LF* | 26, 23, 36 | 22, 21, 21 | 17, 18, 19 | 16, 16, 17 |

TABLE 4 SHORT-TIME TENSION-TEST DATA FOR THE FOUR STEELS AT 750, 850, AND 950 F

| Steel | Test temperature, F | Yield strength, lb per sq in.[a] | Yield strength, lb per sq in.[b] | Tensile strength, lb per sq in. | Elongation in 2 in., per cent | Reduction of area, per cent |
|---|---|---|---|---|---|---|
| *C* (flange) | 750 | 23100 | 25400 | 66600 | 26.0 | 30.8 |
| *C* (body) | 750 | 22900 | 25000 | 64200 | 14.0 | 17 7 |
| Average | | 23000 | 25200 | 65400 | 20 0 | 24.2 |
| *SC* (flange) | 750 | 21300 | 23100 | 63200 | 38.0 | 51.1 |
| *SC* (body) | 750 | 21700 | 23500 | 62500 | 29.5 | 44.0 |
| Average | | 21500 | 23300 | 62900 | 33.7 | 47.5 |
| *F* (flange) | 750 | 24000 | 27200 | 69550 | 30.5 | 46.9 |
| *F* (body) | 750 | 24000 | 27200 | 69900 | 39.5 | 72.7 |
| Average | | 24000 | 27200 | 69700 | 35 0 | 59.8 |
| *LF* (flange) | 750 | 20300 | 22500 | 63500 | 37.0 | 64.2 |
| *LF* (body) | 750 | 19800 | 22300 | 62300 | 39.5 | 63 8 |
| Average | | 20050 | 22400 | 62900 | 38.2 | 64 0 |
| *C* (flange) | 850 | 22900 | 25900 | 55600 | 12.5 | 16.3 |
| *C* (body) | 850 | 21100 | 23100 | 53800 | 12.5 | 18.1 |
| Average | | 22000 | 24500 | 54700 | 12.5 | 17.2 |
| *SC* (flange) | 850 | 19700 | 21200 | 50900 | 31.0 | 57 0 |
| *SC* (body) | 850 | 20500 | 22100 | 54900 | 34.0 | 53.8 |
| Average | | 20100 | 21650 | 52900 | 32.5 | 55.4 |
| *F* (flange) | 850 | 23900 | 26800 | 59800 | 48.0 | 76 4 |
| *F* (body) | 850 | 23100 | 26400 | 60400 | 39.0 | 76 0 |
| Average | | 23500 | 26600 | 60100 | 43.5 | 76 2 |
| *LF* (flange) | 850 | 20900 | 23000 | 53950 | 31.0 | 58.1 |
| *LF* (body) | 850 | 20700 | 22700 | 53000 | 38 0 | 67 9 |
| Average | | 20800 | 22850 | 53470 | 34 5 | 63.0 |
| *C* (flange) | 950 | 20800 | 22700 | 44000 | 11.5 | 16.6 |
| *C* (body) | 950 | 19800 | 21700 | 43900 | 26.5 | 38.8 |
| Average | | 20300 | 22200 | 43950 | 19.0 | 27.7 |
| *SC* (flange) | 950 | 18800 | 20400 | 41300 | 50.0 | 65.6 |
| *SC* (body) | 950 | 19000 | 20400 | 42000 | 45.0 | 72.3 |
| Average | | 18900 | 20400 | 41650 | 47.5 | 68.9 |
| *F* (flange) | 950 | 21600 | 24100 | 48600 | 42.0 | 75.5 |
| *F* (body) | 950 | 21800 | 24100 | 48700 | 50.0 | 79.3 |
| Average | | 21700 | 24100 | 48650 | 46.0 | 77.4 |
| *LF* (flange) | 950 | 18900 | 21000 | 44000 | 35.5 | 57.5 |
| *LF* (body) | 950 | 18800 | 20400 | 41700 | 45.5 | 73.3 |
| Average | | 18850 | 20700 | 42850 | 40 5 | 65.4 |

[a] Stress to produce permanent set of 0.1 per cent.
[b] Stress to produce permanent set of 0.2 per cent.

properties for the two forged steels. About equal values are shown at 950 F by the spheroidized cast steel *SC*. The lowest ductility values are shown by the cast steel *C*.

Impact-test specimens were taken from both the flanges and the bodies of the valve bodies or tees for the tests at room temperature. For tests at the elevated temperatures, specimens were taken only from the flanges.

Data for Charpy impact resistance at room temperature, 750, 850, and 950 F given in Table 5 show the best resistance for the two forged steels. The spheroidized cast steel *SC* shows slightly lower impact resistance except at 950 F where the value is about equal to that for the forged steels. The lowest impact resistance is shown by the cast steel *C*.

The reduction of impact resistance at the higher temperatures was not large. The values at room temperature for the four materials ranged from 14 to 24 ft-lb and at 950 F from 11 to 16 ft-lb.

## RESULTS OF THE CREEP TESTS

The time-deformation curves for the creep tests at 750, 850, and 950 F are shown in Figs. 12, 13, and 14. The details of all the creep tests are shown in Table 6.

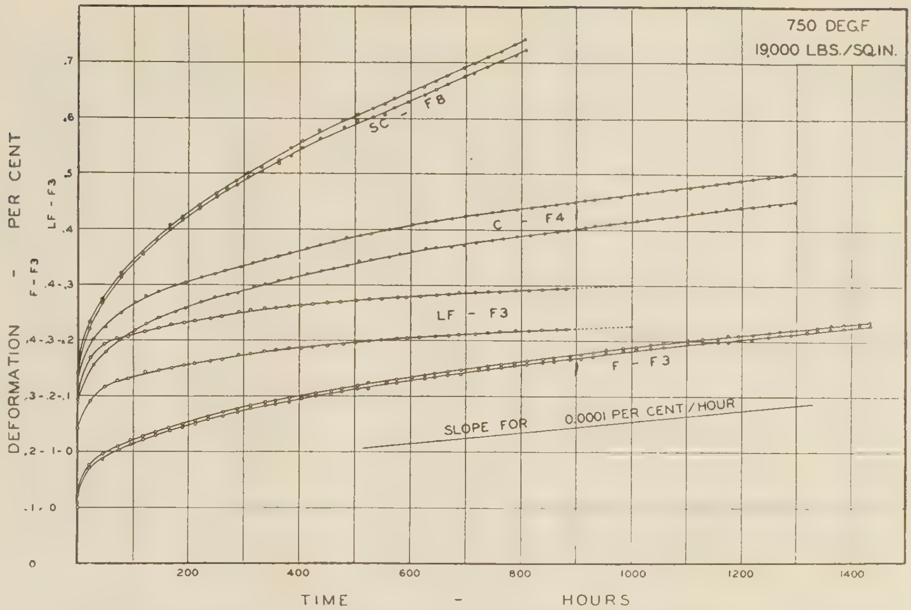



FIG. 12 TIME - DEFORMATION CURVES AT 750 F AND 19,000 LB PER SQ IN. FOR CAST AND FORGED CARBON STEELS

($C$ = cast steel 0.35 per cent C; $SC$ = spheroidized cast steel 0.34 per cent C; $F$ = forged steel 0.37 per cent C; $LF$ = low-carbon forged steel 0.27 per cent C.)

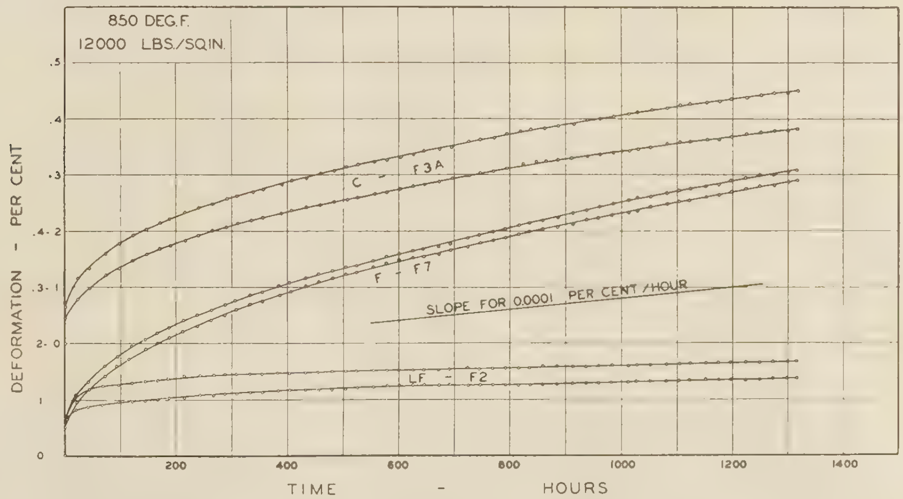



FIG. 13 TIME - DEFORMATION CURVES AT 850 F AND 12,000 LB PER SQ IN. FOR CAST AND FORGED CARBON STEELS

($C$ = cast steel 0.35 per cent C; $SC$ = spheroidized cast steel 0.34 per cent C; $F$ = forged seeel 0.37 per cent C; $LF$ = low-carbon forged steel 0.27 per cent C.)

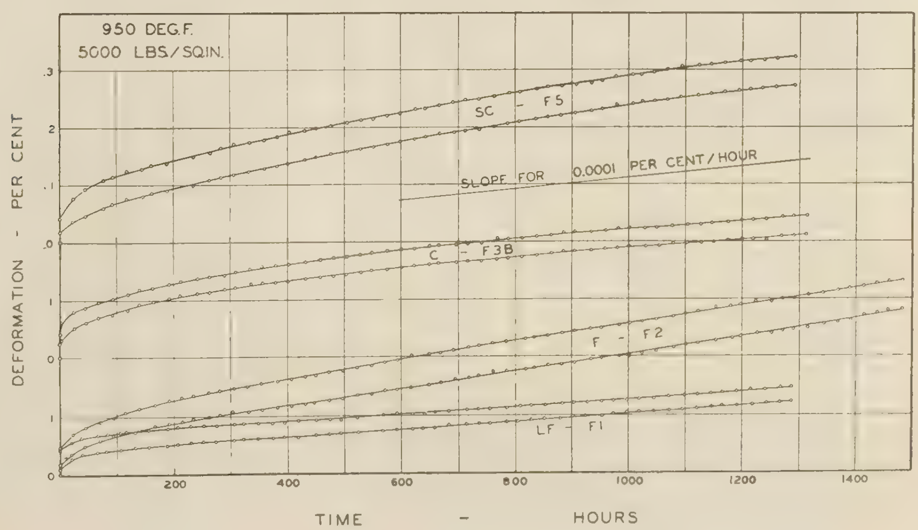



FIG. 14 TIME - DEFORMATION CURVES AT 950 F AND 5000 LB PER SQ IN. FOR CAST AND FORGED CARBON STEELS

($C$ = cast steel 0.35 per cent C; $SC$ = spheroidized cast steel 0.34 per cent C; $F$ = forged steel 0.37 per cent C; $LF$ = low-carbon forged steel 0.27 per cent C.)

TABLE 6 CREEP-TEST DATA FOR CAST AND FORGED CARBON STEELS FROM LARGE VALVES

| Specimen number | Temp. of test, F | Load, lb per sq in. | Duration of test, hr | Initial elongation, per cent: Front | Initial elongation, per cent: Back | At 1000 hours: Rate of deformation, per cent per hour | At 1000 hours: Total deformation, per cent: Front | At 1000 hours: Total deformation, per cent: Back | At 1300 hours: Rate of deformation per cent per hour | At 1300 hours: Total deformation, per cent: Front | At 1300 hours: Total deformation, per cent: Back | Total deformation in 10000 hours, per cent | Izod impact resistance before creep test | Izod impact resistance after creep test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *C*-F4 | 750 | 19000 | 1293 | 0.087 | 0.139 | 0.000130 | 0.414 | 0.466 | 0.000130 | 0.422 | 0.475 | 1.61[b] | 26, 26, 22 | 23, 25 |
| *SC*-F8 | 750 | 19000 | 810 | 0.120 | 0.141 | 0.000433[a] | 0.746[a] | 0.725[a] | ... | ... | ... | 4.625[b] | 23, 25, 26 | 21 |
| *F*-F3 | 750 | 19000 | 1436 | 0.123 | 0.108 | 0.000120 | 0.384 | 0.388 | 0.000100 | 0.410 | 0.420 | 1.466[b] | 27, 32, 32 | 31, 32 |
| *LF*-F3 | 750 | 19000 | 1000 | 0.141 | 0.193 | 0.000050 | 0.330 | 0.400 | ... | ... | ... | 0.815[b] | 41, 55, 50 | 32, 45 |
| *C*-F3A | 850 | 12000 | 1315 | 0.065 | 0.046 | 0.000165 | 0.410 | 0.345 | 0.000130 | 0.450 | 0.385 | 1.548[c] | 26, 26, 22 | 20, 25 |
| *F*-F7 | 850 | 12000 | 1315 | 0.060 | 0.060 | 0.000200 | 0.455 | 0.430 | 0.000200 | 0.510 | 0.492 | 2.241[c] | 27, 32, 32 | 28, 31 |
| *LF*-F2 | 850 | 12000 | 1315 | 0.063 | 0.052 | 0.000020 | 0.125 | 0.165 | 0.000020 | 0.137 | 0.172 | 0.328[c] | 41, 55, 50 | 36, 39 |
| *C*-F3B | 950 | 5000 | 1316 | 0.041 | 0.024 | 0.000085 | 0.225 | 0.191 | 0.000075 | 0.246 | 0.212 | 0.8815[c] | 26, 26, 22 | 23, 24 |
| *SC*-F5 | 950 | 5000 | 1316 | 0.017 | 0.041 | 0.000150 | 0.235 | 0.285 | 0.000110 | 0.265 | 0.320 | 1.2490[c] | 23, 25, 26 | 23, 20 |
| *F*-F2 | 950 | 5000 | 1485 | 0.047 | 0.017 | 0.000140 | 0.258 | 0.202 | 0.000160 | 0.305 | 0.250 | 1.6700[c] | 27, 32, 32 | 29, 31 |
| *LF*-F1 | 950 | 5000 | 1286 | 0.044 | 0.011 | 0.000070 | 0.125 | 0.105 | 0.000070 | 0.130 | 0.150 | 0.7490[c] | 41, 55, 50 | 47, 50 |

[a] At 810 hours (discontinued).
[b] Computed from data at 1000 hours.
[c] Computed from data at 1300 hours.

To facilitate comparisons between the different steels, tests at each of the test temperatures were conducted at one load only, chosen to produce a rate of about 0.0001 per cent per hour at 1000 to 1500 hours.

At 750 F the load was 19,000 lb per sq in.; at 850 F, 12,000 lb per sq in.; and at 950 F, 5000 lb per sq in. Steel *SC* was not tested at 850 F. Most of the tests were run 1300 to 1500 hours except for steel *SC* at 750 F, which showed a fast rate of deformation and was discontinued after 810 hours and steel *LF* at 750 F, which at the time had run only 880 hours. Therefore, at 750 F the four steels have been compared at both 1000 and 1300 hours.

In Table 6 are shown the rates of deformation for the various steels at 750 F and also their total deformation in 10,000 hours computed by extrapolation of the time-deformation curves to 10,000 hours at the final rate of deformation shown.

At 750 F the best creep resistance is shown by steel *LF* (low-carbon forging), although this steel shows a greater initial deformation upon application of the load. It will be recalled that steel *LF* showed the lowest yield strength at 750 F as shown in Fig. 11. Steel *F* (forging) shows the next best creep resistance with cast steel *C* close behind. The poorest creep resistance is shown by the spheroidized cast steel *SC*. In the tests at 850 F, curves for which are shown in Fig. 13 note how quickly the forged steel *LF* strain-hardens with the consequent rapid decrease in rate of deformation. At 850 F the best creep resistance is again shown by steel *LF*, with the cast steel *C* next, and with the forged steel *F* last. Their initial deformations upon loading are very similar. Note in Table 6 the rates of deformation and estimated total deformations in 10,000 hours for the different steels.

At 950 F the low-carbon forging *LF* shows the best creep resistance with the cast steel *C* almost equal to it. Cast steel *SC* shows the next best creep properties, and forged steel *F* the poorest creep properties. As at 850 F there is very little difference between their initial deformations.

TABLE 7 STEELS LISTED IN THE ORDER OF THEIR CREEP RESISTANCE

| Creep resistance | 750 F, 19000 lb per sq in. | 850 F, 12000 lb per sq in. | 950 F, 5000 lb per sq in. |
|---|---|---|---|
| 1 Greatest | *LF*[a] | *LF* | *LF* |
| 2 | *F*[b] | *C* | *C* |
| 3 | *C*[c] | *F* | *SC* |
| 4 Least | *SC*[d] | | *F* |

[a] Low-carbon forged steel.
[b] Forged steel.
[c] Cast steel.
[d] Spheroidized cast steel.

To summarize the results of the creep tests, the steels are listed in Table 7 in their order of creep resistance at the various test temperatures.

It will be seen that the low-carbon forging *LF* heads the list at all of the test temperatures. The high-carbon forging *F*, which was above the cast steels at 750 F, ranks below the cast steel *C* at 850 F and below both cast steels at 950 F.

## Physical Properties After Creep Test

*Impact.* After creep test two round Izod impact-test specimens were machined from the reduced section of each creep-test specimen. After taking a disk 0.3 in. thick from the center of the reduced section to provide material for metallographic examination, the impact specimens were taken so that the notches were located in the gage length at a distance of about 1/4 in. from the end of the reduced section. The end gripped in the anvil of the impact machine had to be shorter than standard, but tests have given comparative results on specimens of short and standard lengths.

In Table 6 are shown the results of the Izod impact tests on the four steels as heat-treated and before test and also on the specimens cut from the reduced section of the creep-test specimens. The data indicate little or no change in impact resistance to have resulted from the long-time exposure to the various temperatures at the various loads used.

Figs. 15, 16, 17, and 18 show the structures of the four steels after removal from the creep tests conducted at the highest test temperature of 950 F. As compared with the structures shown in Figs. 5, 6, 7, and 8 for the steels as heat-treated there are no noticeable differences.

## General Discussion of the Test Data

Considering the ever-present hope of a short-time creep test or a correlation of short-time tests of some sort with expensive long-time creep tests, it is of interest to compare the results of the short-time tension tests and the creep tests at 750, 850, and 950 F.

Short-time tension-test data on the four steels do not show the relative rating found in the creep tests. High-carbon forged steel *F*, which showed the highest tensile strength and yield strengths along with high ductility values, showed the lowest creep resistance at both 850 and 950 F. Low-carbon forged steel *LF* showed properties between those of the two cast steels, yet it showed the highest creep resistance at all test temperatures.

Considering the chemical compositions of the steels and their structures as shown in Figs. 5, 6, 7, and 8, these results require further comment.

The low creep resistance of the cast steel *SC* at 750 and 850 F was not unexpected, since it has been stated by Tapsell (3) p. 192, that a spheroidized structure does not possess the strength and creep resistance of a structure containing pearlite. The creep resistance of this steel *SC* as compared with forged steel *F* at 950 F is interesting and unexplained by any of the experimental work.

It is recognized generally that, all other variables being equal, increase of carbon content increases tensile properties and creep resistance of carbon steels. However, Clark (11) has previously

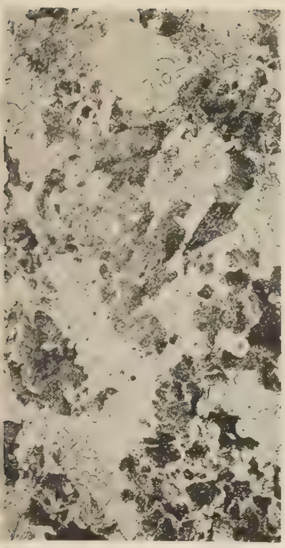


Fig. 15 Cast Steel *C*. Specimen *C*-F3B After Creep Test at 950 F at a Load of 5000 Lb per Sq In. for 1316 Hours. Specimen Etched With 2 Per Cent Nital–100×

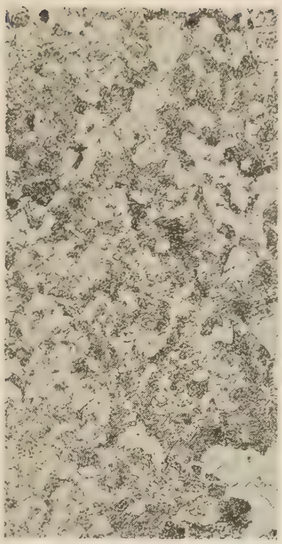


Fig. 16 Cast Steel *SC*. Specimen *SC*-F5 After Creep Test at 950 F at a Load of 5000 Lb Per Sq In. for 1316 Hours. Specimen Etched With 2 Per Cent Nital–100×

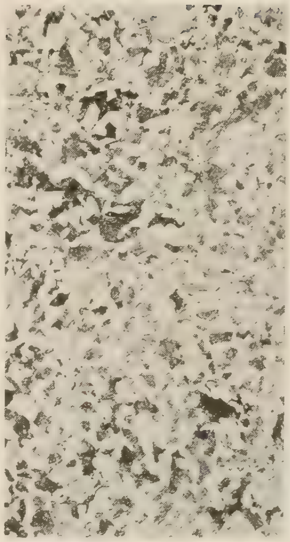


Fig. 17 Forged Steel *F*. Specimen *F*-F2 After Creep Test at 950 F at Load of 5000 Lb per Sq In. for 1485 Hours. Specimens Etched With 2 Per Cent Nital–100×

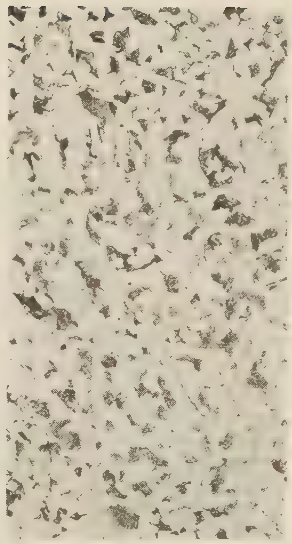
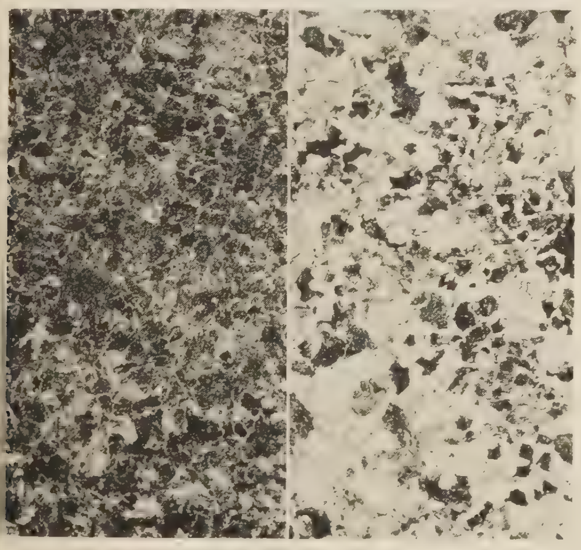


Fig. 18 Forged Steel *LF*. Specimen *LF*-F1 After Creep Test at 950 F at a Load of 5000 Lb per Sq In. for 1286 Hours. Specimen Etched With 2 Per Cent Nital–100×

ointed out that the melting practice used may have an important ffect on the properties of carbon steels in creep tests. He howed better creep resistance for a 0.13 per cent carbon steel nade by alloy-steel practice than for a 0.18 per cent carbon steel nade by usual commercial practice.

The manufacturer of the two forged-steel tees obtained the orging billets from the same steel producer. Data as to the nelting practice for the two forged steels have been given preiously.

In an effort to show any possible differences between the four eels, the McQuaid-Ehn carburizing test was used to develop he normality and inherent grain size of the materials. A dif-



ig. 19 Structure of Cast Steel *C* as Carburized–100×: Etched With 5 Per Cent Picric Acid in Alcohol
(Left: Case of specimen. Right: Core of specimen.)

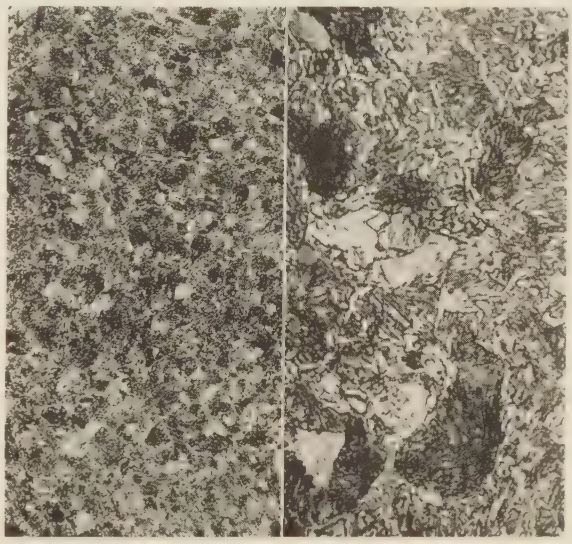


Fig. 20 Structure of Cast Steel *SC* as Carburized; Etched With 5 Per Cent Picric Acid in Alcohol
(Left: Case of specimen–100×. Right: Case of specimen–500×.)

ference between the steels not indicated by their structures as heat-treated was immediately evident. Figs. 19, 20, 21, and 22 at a magnification of 100× show the core and case of the four steels after carburizing 10 hours at 1725 F and cooled in the pot in the furnace.

Fig. 19 shows the case and core of the cast steel *C*. The structure was fine-grained and normal. As in Fig. 5, the core showed a banded structure and a nonuniform grain size with many small grains intermingled with larger grains.

Fig. 20 shows the case of cast steel *SC* at magnifications of both 100× and 500×. The core was similar to cast steel *C* and is not shown. The steel was slightly abnormal.

Figs. 21 and 22 show the case and core of the two forged steels. Both are normal, but the low-carbon forged steel *LF* shows a very coarse grain, while steel *F* shows a fine grain very similar to cast steels *C* and *SC*.

These data indicate a very definite difference between the materials. Steel *LF* with the coarse grain as indicated by the McQuaid-Ehn test shows the best creep properties. It should be noted that the structures of the steels as heat-treated do not indicate this difference and provide no clear-cut evidence of the superiority in creep resistance of the low-carbon forged steel *LF* which showed a coarse grain after the carburizing tests. It is not suggested here that a coarse-grained and normal steel as determined by the carburizing test will show superior creep resistance. Rather, the McQuaid-Ehn test has been used as an indication that there are definite differences in the steels, possibly due to melting practice and deoxidation, but not indicated by their structures of any of the physical properties determined at room temperature.

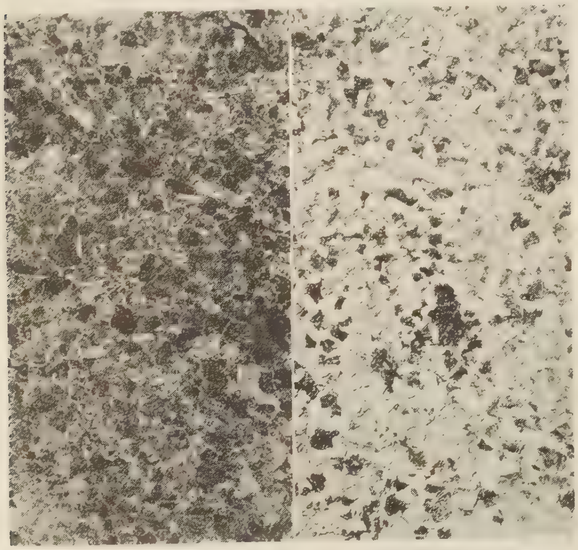


Fig. 21 Structure of Forged Steel *F* as Carburized; Etched With 5 Per Cent Picric Acid in Alcohol–100
(Left: Case of specimen. Right: Core of specimen.)

It may be that the superiority of forged steel *LF* as compared with forged steel *F* is not due to the apparent slightly greater grain size shown in Figs. 7 and 8 as heat-treated. These data suggest the interesting possibility that if two forged steels of similar composition and properties in short-time tests had the same original grain size, but the carburizing test indicated a difference in their normality, a difference in creep resistance might be shown.

Another interesting comparison is the fact that cast steel *C* and forged steel *LF* in the heat-treated condition show approximately the same grain size, but the forged steel *LF* showed more even distribution of the pearlite patches. The better creep resistance of the more uniform forged steel *LF* agrees with the findings of Wyman (19), who states: "To have a material of high creep strength, it is essential to have a steel which is structurally uniform and free from banding or dendritic segregation."

It may be seen from the test data herein presented that no broad generalization can be made as to superiority for service at elevated temperatures for either forged or cast carbon steels in the form of valve bodies or tees. While it is true that the low-carbon forged steel *LF* showed the best creep properties over the whole temperature range 750 to 950 F, the slightly better creep resistance of the cast steels as compared with the high-carbon forged steel *F* at 950 F and of cast steel *C* as compared with forged steel *F* at 850 F make incorrect any generalization in favor of either cast or forged carbon steels as a class for service at 750 to 950 F.

The differences in creep properties between the four steels are really not large as shown in Table 6 except in the case of the large creep rate for the spheroidized cast steel *SC* at 750 F. Since their creep properties do not differ widely and are not consistently in favor of one type of material, no doubt other factors such as soundness, resistance to shock, tensile strength, yield strength, and ductility both at room and at elevated temperatures will enter into the choice of materials for each specific use.

The conclusions of Tapsell (3) that generalizations as to a better relative position of either cast or wrought steel, and those of White, Clark, and Wilson (9) that generalizations as to virtue of coarse grain size, are unwarranted in the temperature range of commercial use, cited in the early part of this paper, seem to be borne out by these experiments.

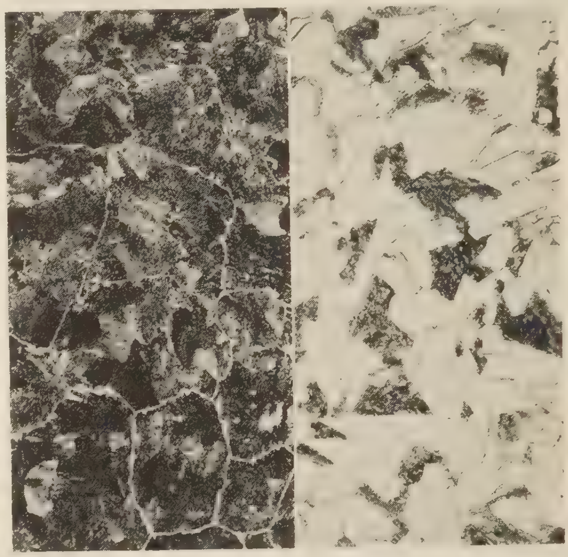


Fig. 22 Structure of Forged Steel *LF* as Carburized; Etched With 5 Per Cent Picric Acid in Alcohol–100×
(Left: Case of specimen. Right: Core of specimen.)

Only when we cease to make generalizations that do not hold consistently and search further into the factors that make one casting or one forging superior to another in high-temperature properties will we be on the road to lasting progress.

## Summary

1 Tensile properties at room temperature for the three steels with approximately 0.35 per cent carbon were quite similar. Lower strength values and higher ductility values were shown by the forged steel with 0.27 per cent carbon. The forged steels showed slightly higher values than the cast steels.

2 The forged steel *F* (0.37 per cent carbon) showed the best short-time tensile strength and ductility in tests at 750, 850, and 950 F. The other three steels showed comparable strengths, and the ductility of cast steel *C* (0.35 per cent carbon) was considerably lower than for the spheroidized cast steel *SC* (0.34 per cent carbon) or forged steel *LF* (0.27 per cent carbon).

3 The two forged steels show the best Charpy impact resistance at room temperatures, 750, 850, and 950 F. Slightly

lower impact resistance is shown by the spheroidized cast steel *SC* except at 950 F. The lowest impact resistance is shown by cast steel *C*. The reduction of impact resistance at the higher temperature was not large.

4 Forged steel *LF* (0.27 per cent carbon) showed the best creep resistance at temperatures of 750, 850, and 950 F. Forged steel *F* (0.37 per cent carbon) which was next best at 750 F was poorer in creep resistance to the two cast steels *C* (0.35 per cent carbon) and *SC* (0.34 per cent carbon) at 850 and 950 F. The spheroidized cast steel *SC* (0.34 per cent carbon) showed the poorest creep resistance at 750 F.

5 McQuaid-Ehn carburizing tests indicate definite differences between the four steels.

6 There appears to be no correlation between the results of the short-time tension and long-time creep tests at 750, 850, and 950 F.

7 Impact tests and metallographic examination of the steels after creep test indicate little or no change had taken place due to the long-time exposures at the creep-test temperatures.

8 No broad generalization as to superiority of cast versus wrought, or coarse-grained versus fine-grained steels as regards creep resistance is warranted by the test results. Other properties such as soundness, strength, impact resistance, and ductility will undoubtedly enter into the choice of carbon steels for specific uses at the temperatures investigated.

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# Cooperative Study of a Stable 18 Cr 8 Ni Steel Without Stabilizing Additions[1]

IT IS recognized that austenitic steel of the 18 per cent Cr, 8 per cent Ni type is subject normally to a certain degree of alteration, that is, some diminution of its original toughness (evaluated by room-temperature impact tests) when heated for considerable periods in the range 1200–1400 F. Such heating is also known to sensitize the material and put it in a condition where intergranular corrosion may occur and seriously embrittle the material. It is not entirely certain whether the impact effect and the sensitivity to corrosion are manifestations of the same underlying phenomenon, usually considered to be a precipitation of carbide at grain boundaries.

The same remedies, holding the carbon low, or the introduction of titanium, columbium, or some other carbide-forming element to stabilize the carbide, are often resorted to for combating either type of alteration.

In its study of the high-temperature properties of 18 Cr 8 Ni steel as an important and typical member of the family of austenitic steels, the Joint A.S.T.M.-A.S.M.E. Committee on Effect of Temperature on the Properties of Metals found that two heats of 18 Cr 8 Ni steel, water quenched from 2000 F, appeared exceptional in their resistance to high-temperature deterioration.

This abnormal behavior was noted in the A.S.M.E. progress report[2] in December, 1933, in which, among various other high-temperature properties, a very high notched-bar impact resistance of rolled specimens was found to be maintained after the specimens had been subjected to creep tests at temperatures of 1200 F to 1400 F for a period of 600 to 1600 hours. Even with a carbon content of 0.125 per cent, several specimens showed no loss of impact resistance, while the lower-carbon heat (0.06 per cent C) fully retained its great toughness.

Both these heats, made for the Committee by the Babcock & Wilcox Company were induction-furnace melts of straight 18 Cr 8 Ni steel without the addition of any stabilizing element such as titanium or columbium. In the report[2] on that work, it was noted that E. C. Smith had reported 18 Cr 8 Ni steel melted in an induction furnace may show a much slower reduction in toughness than material melted in an arc furnace. Other cases in the literature were cited where plain 18 Cr 8 Ni steel, or that with certain additions, had shown vast differences in the tendency toward change in steels of apparently identical chemical composition.

The experimental results raised the question whether the high impact resistance of specimens tested after creep indicated that the application of stress at high temperatures (or the tiny deformation resulting from that stress) inhibited change, and a further study was made of that factor. This work was reported to the A.S.T.M. in June, 1935,[3] and included not only the nonsensitive low carbon 18 Cr 8 Ni steel (committee designation K19) previously referred to, but also another heat of low-carbon 18 Cr 8 Ni steel (committee designation K9). The K19 steel was heated at 1400 F without stress up to nearly 4000 hours. Its impact resistance fell to about 45 ft-lb Charpy, in the first 100 hours and thereafter did not change.

The K9 steel, water quenched from 2100 F, which previously[4] had been studied after heating unstressed for 1000 hours and which had fallen to about 40 ft-lb Charpy at 1400 F, was stressed for 100 hours at 1400 F at a load of 1600 lb per sq in. before making impact tests, but showed the same behavior as K19 steel in that it still held its toughness after stressing. These observations led to the suggestion that alteration, measured by impact resistance, may go on at a slower rate in a stressed than in an unstressed specimen.

It has previously been remarked[2] by some members of the Committee that thin specimens might be expected to be more susceptible to alteration than more massive ones, and hence, that before the K19 heats could be classed as alteration-resistant, they should be studied in thin sheet or strip form. The impact studies also indicated that such a study should deal with both stressed and unstressed specimens. This work has now been completed and is reported herein.

The K19 material of both high-carbon and low-carbon contents was rolled by the Carpenter Steel Company from 1-in. round bars into strips 1 in. wide and 0.020 in. and 0.040 in. thick. The strips were cut into lengths of 7 in. and were assembled in packs of 20 in a crate or frame of heavy 18:8 stock welded together so as to hold the pack tightly and to minimize warping, this preparation being done by the Westinghouse Electric and Manufacturing Company. The packs were then water quenched from 2000 F at the Battelle Memorial Institute. The specimens, were then returned to Westinghouse Electric and Manufacturing Company and standard sheet specimens having a test section 0.500 in. wide and 3 in. long were machined from them.

The specimens to be stressed were assembled in sets of four on heat-resistant pins passing through holes in the grips and each set was dead-weight loaded to give a unit stress on the test section of each specimen of 10,400 lb per sq in. in an electric furnace operating at 1200 F for various periods. Unstressed specimens were also heated at 1200 F and 1400 F. This work was under the supervision of N. L. Mochel.

The specimens were broken and examined by the Bethlehem Steel Company. Of course, no alteration of a type that would be revealed only by impact could be determined on such thin stock, but it was expected that any loss in toughness would be detectable by loss in elongation when tested at room temperature after

[1] Progress report of the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals, Herbert F. French, chairman.

[2] "High-Temperature Tensile, Creep and Fatigue of Cast and Wrought High- and Low-Carbon 18 Cr 8 Ni Steel From Split Heats," by H. C. Cross, Trans. A.S.M.E., vol. 56, no. 7, 1934, paper RP-56-6, pp. 533–554.

Contributed by the A.S.T.M.-A.S.M.E. Joint Research Committee on Effect of Temperature on the Properties of Metals and presented at the Annual Meeting of The American Society of Mechanical Engineers, held in New York, N. Y., December 2 to 6, 1935.

Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until April 10, 1936, for publication at a later date.



[3] "Effect of Long Time Heating With and Without Stress on Impact Resistance of 18 Per Cent Cr 8 Per Cent Ni Steel (K9 and K19 Steel)," by H. C. Cross and F. B. Dahle, Appendix 1 to Report of Joint A.S.T.M.-A.S.M.E. Committee on Effect of Temperature on the Properties of Metals, Proceedings, A.S.T.M., vol. 35, part 1, 1935, pp. 126–132.

[4] "Cooperative Study of Charpy Notched-Bar Impact Tests, Magnetic Permeability Tests, and Structural Stability in the Absence of Stress, of 18 Cr 8 Ni Stainless Steels," Proceedings, A.S.T.M., vol. 32, part 1, 1932, pp. 156–192.

TABLE 1 PHYSICAL PROPERTIES OF THE K19 STEELS

| | Heating temp, F | Hours heated | Load, lb per sq in. | Tensile strength, lb per sq in. | Elongation in per cent in 1 in. | 2 in. | 3 in. |
|---|---|---|---|---|---|---|---|
| Low-carbon (0.067 per cent) series, 0.020 in. thick | As quenched | Not heated | No load | 94380 | 58 | 52 | 50.0 |
| | 1200 | 100 | No load | 97000 | 59 | 50 | 47.0 |
| | 1200 | 100 | 10400 | 95380 | 46 | 39 | 35.0 |
| | 1400 | 100 | No load | 92380 | 54 | 46 | 43.5 |
| Low-carbon series, 0.040 in. thick | As quenched | Not heated | No load | 93000 | 64 | 55 | 50.5 |
| | 1200 | 100 | No load | 96890 | 41 | 37.5 | 36.5 |
| | 1200 | 100 | 10400 | 94000 | 59 | 52 | 47.5 |
| | 1400 | 100 | No load | 93680 | 52 | 51 | 45.5 |
| High-carbon (0.125 per cent) series, 0.020 in. thick | As quenched | Not heated | No load | 90160 | 33[a] | 33[a] | 33.0[a] |
| | 1200 | 100 | No load | 97000 | 27[b] | 26.5[b] | 26.0[b] |
| | 1200 | 100 | 10400 | 97390 | 51 | 49 | 45.5 |
| | 1400 | 100 | No load | 90900 | 48 | 44 | 40.5 |
| High-carbon series, 0.040 in. thick | As quenched | Not heated | No load | 95500 | 66 | 55 | 51.5 |
| | 1200 | 100 | No load | 95380 | 60 | 52 | 48.5 |
| | 1200 | 100 | 10400 | 95380 | 54 | 48.5 | 44.5 |
| | 1200 | 384 | 10400 | 102850 | 54 | 48 | 42.5 |
| | 1200 | 384 | 10400 | 101500 | 55 | 44 | 37.5 |
| | 1200 | 384 | 10400 | 100500 | 53 | 39 | 34.5 |
| | 1200 | 384 | 10400 | 102300 | 55 | 43 | 37.5 |
| | 1200 | 384 | 10400 | 102850 | 54 | 43 | 37.5 |
| | 1200 | 384 | 10400 | 104250 | 56 | 50 | 45.5 |
| | 1200 | 384 | 10400 | 103780 | 54 | 47.5 | 42.5 |
| | 1200 | 384 | 10400 | 102900 | 51 | 40 | 34.5 |
| | 1200 | 1008 | 10400 | 101450 | 53 | 45.5 | 40.0 |
| | 1200 | 1008 | 10400 | 102400 | 52 | 43 | 38.0 |
| | 1200 | 1008 | 10400 | 102400 | 36 | 33 | 30.0 |
| | 1200 | 1008 | 10400 | 98600 | 43 | 43 | 38.5 |
| | 1400 | 100 | No load | 97560 | 47 | 44.5 | 40.5 |

[a] Broke in grips.
[b] Broke at deep center-punched gage mark.

the sojourn at high temperature, and by a dead rather than by a ringing sound when the specimens were dropped on a cement floor. The results reported by P. E. McKinney of the Bethlehem Steel Company are given in Table 1.

Mr. McKinney states that no appreciable loss of ductility nor impairment of physical properties was found regardless of the time or temperature of heating, or whether the specimen was stressed or not, and that he is at a loss to explain the behavior of the K19 material, especially of the high-carbon (0.125 per cent) heat as most of such material, heated within these sensitizing ranges, would be impaired. The specimens had a live ring when dropped on a cement floor.

Therefore, it would appear that the K19 heats are extremely resistant to deterioration when subjected to temperatures of 1200 F or 1400 F for extended periods of time. Whether this remains true for shorter heating cycles is not yet known and it is believed that this point should be carefully verified before concluding that the K19 heats are outstanding in their behavior.

Future work should include a study of both impact and ductility, as well as corrodability after exposure to temperatures in the sensitizing range for various periods of time. The Committee hopes to be able to undertake this work and report on it hereafter. Such work should throw light on the question whether alteration without corrosion and sensitivity to corrosion are manifestations of the same phenomenon or of two separate phenomena.

# Discussion

## Radiation Intensities and Heat Transfer by Radiation in Boiler Furnaces[1]

Addenda[2]

In the paper some assumptions were made to obtain Equations [5] and [6] (the tentative heat-transfer equations) from the radiation-intensity equation. The resultant equation for heat transfer leads to erroneous conclusions.

Additional experiments have made possible the modification of the tentative equations. In these experiments, the heat absorbed by radiation by a steel surface at various radiation intensities has been observed. A number of tests were made with the steel surface partially covered with slag and ash.

The calorimeter employed in these tests is shown in this addenda as Fig. 14. It consists of a hollow steel block *S* through which water circulates. The outer surface of this steel block has a thick layer of black oxide which was formed when the steel was maintained at a dull red heat for about 1 hour. This block is surrounded on all sides, except for the front surface, by a water-cooled jacket *J* which is insulated from the steel block with 85 per cent magnesia.

Heat transfer by convection to the front surface of the steel block was minimized by a shield of cold air produced by a series of air jets. These jets provided an outward flow of cold air which prevented the hot furnace gases from making contact with the surface tested. Since air is transparent to radiation, and the air shield was arranged to keep the absorbing surface free of hot gases, the heat absorbed by the steel surface was practically all transmitted by radiation.

*Tests in the Boiler Furnace.* The heat-transfer tests were made at observation door No. 2, the location of which is shown in Fig. 6 of the paper. The probe was placed in the opening in the furnace wall so that its front surface was approximately in line with the inner surface of the furnace wall. Alternate readings, each about 3 minutes in duration, were taken through this door with the probe and with the quartz-window radiation calorimeter.

A number of sets of observations were made with the clean oxidized steel surface. The data for these tests are given in Table 5 in this addenda. In this tabulation $X_r$ is the measured heat-transfer rate by radiation to the steel surface of the probe, and $I$ is the radiation intensity as determined with the quartz-window calorimeter. The average value of the ratio $X_r/I$ for the six tests is 0.89. In other words, the radiation absorption coefficient for the clean oxidized steel surface is 0.89.

A series of tests was also made with the steel surface partially covered with slag and ash. The ash formations were fastened to the steel surface by a layer of refractory cement about $^1/_{16}$ in. thick. In test No. *D*-1 a dense black slag about 0.5 in. thick covered nine-tenths of the surface. In the remaining tests, the ash coverings consisted of a porous material which had

[1] Published as paper FSP-57-4, by Huber O. Croft and C. F. Schmarje, in the April, 1935, issue of the A.S.M.E. Transactions.

[2] Presented by the authors as addenda to the paper.[1]

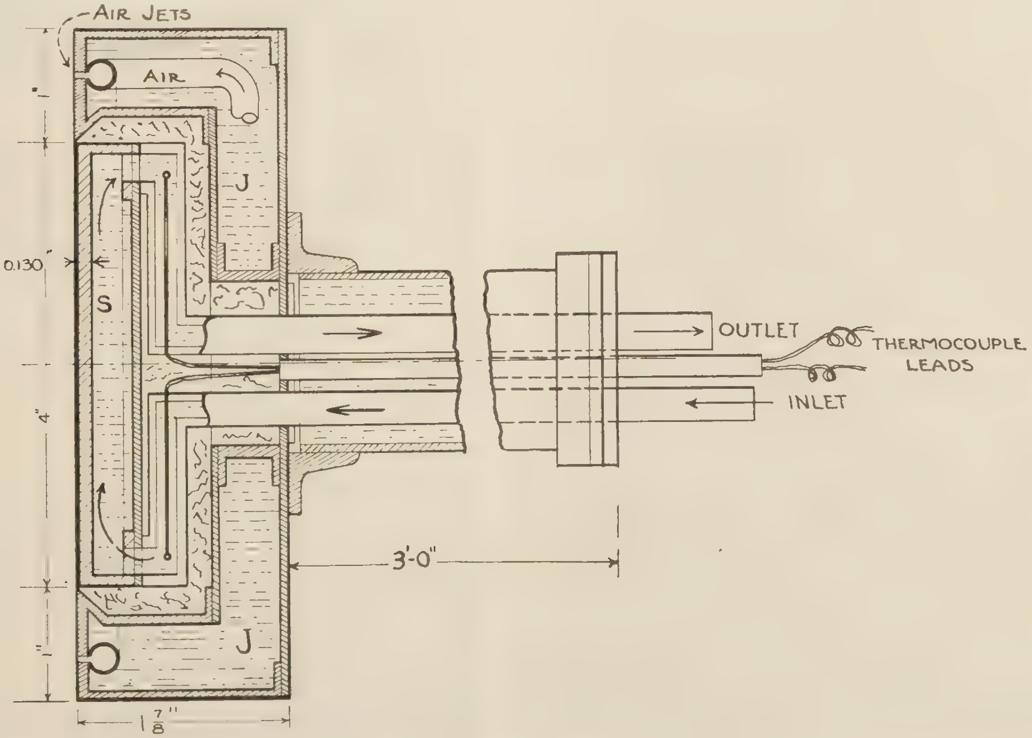


Fig. 14 Thermal Probe

TABLE 5 TESTS WITH A CLEAN OXIDIZED STEEL SURFACE

| Test | $X_r$ | $I$ | $X_r/I$ |
|---|---|---|---|
| C-1 | 34.35 | 36.1 | |
| | 33.9 | 39.7 | |
| | 32.7 | .. | |
| | 33.6 | 37.9 | 0.887 |
| C-2 | 60.6 | 66.1 | |
| | 58.6 | 61.8 | |
| | 53.3 | .. | |
| | 57.5 | 63.9 | 0.899 |
| C-3 | 53.6 | 50.0 | |
| | 43.9 | 50.3 | |
| | 49.9 | 47.0 | |
| | 41.4 | 55.1 | |
| | 39.4 | 56.6 | |
| | .. | 49.5 | 0.887 |
| | 45.6 | 51.4 | |
| C-4 | 57.5 | 67.4 | |
| | 42.0 | 58.1 | |
| | 38.1 | 42.6 | |
| | 36.1 | 38.8 | |
| | .. | 37.2 | |
| | 43.4 | 48.8 | 0.889 |
| C-5 | 47.5 | 45.3 | |
| | 40.6 | 47.7 | |
| | 39.8 | 42.7 | |
| | 38.4 | 46.7 | |
| | 42.6 | 42.6 | |
| | 39.4 | 53.6 | |
| | 41.4 | 46.4 | 0.893 |
| C-6 | 24.9 | 33.4 | |
| | 28.2 | 34.8 | |
| | 43.3 | 44.4 | |
| | 43.4 | 46.6 | |
| | 36.1 | 36.9 | |
| | 28.4 | 34.0 | |
| | 34.06 | 38.35 | 0.888 |

$X_r$ = heat-absorption rate determined with the thermal probe, 1000 Btu per sq ft per hr.
$I$ = radiation intensity determined with quartz-window calorimeter, 1000 Btu per sq ft per hr.

TABLE 6 TESTS WITH PARTIALLY DIRTY STEEL SURFACES

| Test | $D$ | $X_r$ | $I$ | $X_r/I$ |
|---|---|---|---|---|
| D-1 | 0.9 | 15.65 | 45.6 | |
| | | 16.0 | 46.1 | |
| | | 16.1 | 48.9 | |
| | | 15.3 | 46.8 | |
| | | 14.3 | ... | |
| | | 15.47 | 46.85 | 0.330 |
| D-2 | 0.9 | 18.5 | 38.6 | |
| | | 18.3 | ... | |
| | | 14.1 | 52.4 | |
| | | 15.0 | ... | |
| | | 14.0 | 46.5 | |
| | | 14.7 | ... | |
| | | 15.77 | 46.17 | 0.341 |
| D-3 | 0.76 | 14.2 | ... | |
| | | 15.0 | 51.5 | |
| | | 13.9 | ... | |
| | | 16.2 | 50.5 | |
| | | 19.1 | ... | |
| | | 16.3 | 48.6 | |
| | | 14.4 | ... | |
| | | 14.6 | 53.2 | |
| | | 15.46 | 50.95 | 0.304 |
| D-4 | 0.30 | 36.9 | ... | |
| | | 42.4 | 63.6 | |
| | | 37.9 | ... | |
| | | 41.7 | 64.0 | |
| | | 41.2 | ... | |
| | | 40.0 | 63.8 | 0.626 |
| D-5 | 0.475 | 29.9 | 55.8 | |
| | | 27.1 | 56.3 | |
| | | 27.8 | 62.0 | |
| | | 29.6 | 56.5 | |
| | | 28.9 | 66.4 | |
| | | 31.8 | 57.6 | |
| | | 29.18 | 59.0 | 0.494 |
| D-6 | 0.423 | 39.3 | 63.5 | |
| | | 40.4 | 59.0 | |
| | | 39.85 | 61.25 | 0.651 |

$D$ = fraction of the surface covered with slag or ash
$X_r$ = heat-absorption rate determined with the thermal probe, 1000 Btu per sq ft per hr
$I$ = radiation intensity determined with the quartz-window calorimeter, 1000 Btu per sq ft per hr

been formed of particles of fly ash stuck together on cooled surfaces in the furnace. The thicknesses of the ash coverings were $^5/_8$ in. in test $D$-2, $1^3/_4$ in. in test $D$-3, $1^3/_8$ in. in test $D$-4, $1^3/_4$ in. in test $D$-5, and $^3/_{16}$ in. in test $D$-6. The data for these tests are given in Table 6.

The ratio $X_r/I$ is plotted against the dirtiness $D$ in Fig. 15. These data may be represented by the straight-line equation

$$X_r/I = 0.89\,(1 - 0.8D) \qquad [7]$$

This ratio $X_r/I$ actually varies with the thickness of the slag or ash layer, but since this variation is apparently not very great, an average such as taken in Fig. 15 will serve for the purposes of this investigation.

During the tests represented by Equation [7], the cooling-water temperature was about 70 F, while in the actual heating surfaces in the furnace the temperature was about 400 F. Making a correction for this difference in temperature on the basis of the Stefan-Boltzmann law, it is found that Equation [7] should be decreased by about 2 per cent, so that

$$X_r/I = 0.98 \times 0.89\,(1 - 0.8D) = 0.872\,(1 - 0.8D) \qquad [8]$$

Substituting in Equation [8] the value of $I$ as given by the tentative Equation [3] there results

$$X_r = 0.872\,\frac{(1 - 0.8D)\,(0.5 + 1.7D)}{1 + (A\sqrt{C_r}/27)}\,C_rU \qquad [9]$$

*Radiation and Convection in a Clean Furnace.* For the special case in which the furnace is clean, that is $D = 0$, Equation [9] reduces to

$$_oX_r = \frac{0.436\,C_rU}{1 + (A\sqrt{C_r}/27)} \qquad [10]$$

where $_oX_r$ is the heat-transfer rate by radiation in Btu per sq ft per hr to the cold surfaces in a clean furnace.

However, the similar Hudson-Orrok formula, which gives the total heat transferred by radiation and convection is

$$X = \frac{C_rU}{1 + (A\sqrt{C_r}/27)} \qquad [11]$$

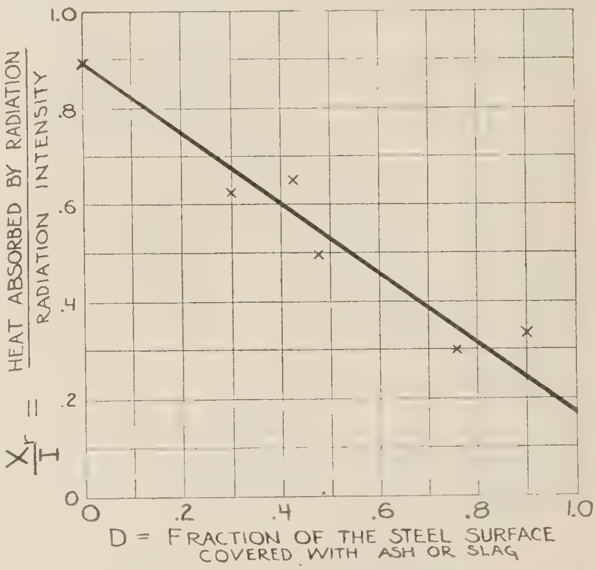


FIG. 15 VARIATION OF HEAT TRANSFER BY RADIATION FOR AN ASH-COVERED STEEL SURFACE

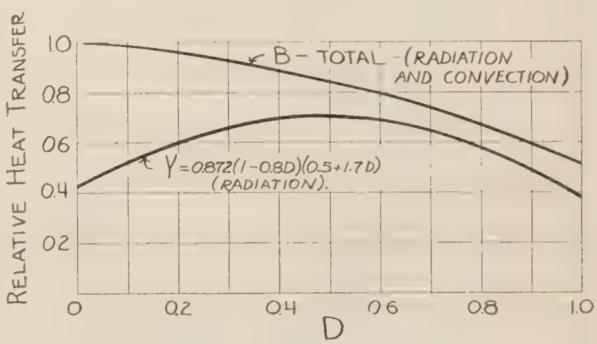


FIG. 16 RADIATION AND TOTAL HEAT TRANSFER (NOT CORRECTED)

A comparison of Equations [10] and [11] shows that the heat transferred by radiation $X_r$ is 43.6 per cent of the total heat transferred (radiation and convection) as computed from the Hudson-Orrok formula for these tests. This division of the total heat transfer between radiation and convection for $D = 0$ (clean furnace) is shown graphically in Fig. 16.

To investigate the division of the total heat transfer between radiation and convection for dirty furnaces, it will be necessary to find how the total heat transferred to the cold surfaces in the furnace varies with the furnace dirtiness.

*Effect of Dirtiness on Total Heat Transfer in the Furnace.* A probable relationship between the total heat absorbed in the furnace and the dirtiness is shown by curve $B$ in Fig. 16. This curve expresses the commonly observed fact that as the water-wall tubes become dirty, less heat is absorbed by the cold surfaces in the furnace for a given energy-release rate.

The effect of the decrease of total heat transferred in the furnace as the furnace becomes dirty is illustrated in a series of tests reported by DeBaufre.[3] These tests show that the effect of "considerable amounts of slag" is to reduce by about 20 per cent the total heat transferred to the cold surfaces in the furnace. For this condition, $D$ was probably more than 0.4 and less than 0.8. A reasonable value for $D$ would be 0.6. Then for $D = 0.6$, the total heat transfer is 80 per cent as much as it is for the clean furnace with the same energy-release rate. This establishes the trend of curve $B$ in Fig. 16.

The corresponding dependence of the radiation upon the furnace dirtiness, as predicted by Equation [9], is shown by curve $Y$ in Fig. 16. The factor in Equation [9] (the radiation equation) involving the dirtiness is

$$Y = 0.872\,(1 - 0.8D)\,(0.5 + 1.7D) \qquad [12]$$

*Modification of Radiation Equation.* The need for some correction is indicated from a consideration of the relative magnitude of the rates of heat transfer by radiation and by convection in a dirty furnace. For instance, for $D = 0.5$, the half of the surface which is clean will absorb at least as much heat by convection as it does when all the surface is clean. Hence, the average heat-transfer rate by convection for $D = 0.5$ would be at least one half as much as it would be for $D = 0$ with the same energy-release rate.

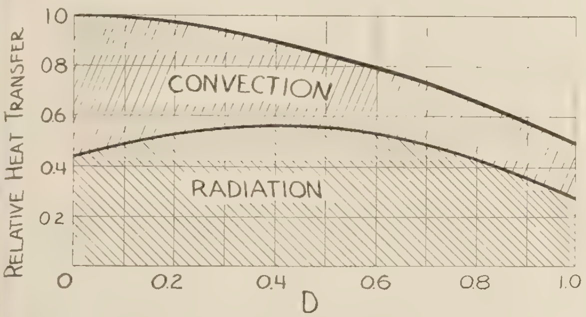


Fig. 17 Comparison of Heat Transferred by Radiation and Convection in the Furnace

But this is not the conclusion which would be drawn from an inspection of Fig. 16. The curves in Fig. 16 show the convection to be only 27 per cent as much at $D = 0.5$ as at $D = 0$.

Since the curves of Fig. 16 lead to incorrect conclusions, at least one of them is wrong. Curve $B$ was drawn with little information, but if it were to be shifted upward far enough to correct this discrepancy at $D = 0.5$, the change would be such that there would be no significant decrease in the total heat transfer in the furnace as $D$ increases. Hence, it is concluded that $Y$ is the offending curve and should be modified to correct this apparent defect.

Such a modification is shown in Fig. 17. The resulting value of $Y$ from this graph is

$$Y' = 0.872\,(1 - 0.8D)\,(0.5 + 1.1D) \qquad [13]$$

[3] "Heat Absorption in Water-Cooled Furnaces," by W. L. DeBaufre, Trans. A.S.M.E., vol. 53, 1931, paper FSP-53-19a, p. 257 (Manchester Tests).

This change from $Y$ to $Y'$ has been accomplished by changing the radiation-intensity factor $(0.5 + 1.7D)$ to $(0.5 + 1.1D)$. This

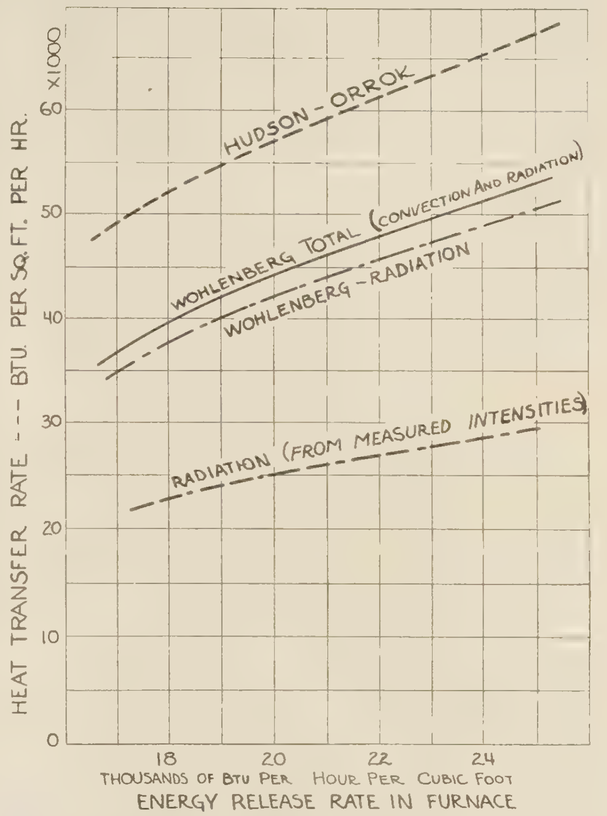


Fig. 18 Comparison of Radiation Based Upon the Measured Radiation Intensities With the Hudson-Orrok and Wohlenberg Formulas
(Data obtained from a clean furnace, $D = 0$.)

change may be justified on the grounds that the estimates of the fraction dirty during the boiler tests could be in error. The indications are that these estimates were low. It is unlikely that the necessary change should be made in the factor $(1 - 0.8D)$ for the reason that when it was determined the dirty area of the thermal probe was measured, rather than estimated.

When $Y'$ is substituted in Equation [9] in place of $Y$, the radiation equation becomes

$$X_r = 0.872\,\frac{(1 - 0.8D)\,(0.5 + 1.1D)}{1 + (A\sqrt{C_r}/27)}\,C_r C \qquad [14]$$

This radiation equation has been set up from considerations of the variation of radiation and convection with the furnace dirtiness at constant energy-release rate. The relative importance of the heat transfer by radiation and by convection probably varies with the energy-release rate in the furnace. But since the boiler tests of this investigation were made under regular operating conditions, the range of energy-release rates was not great enough to permit a prediction of its effect upon the relative heat transfer by radiation and by convection.

*Comparison of Modified Radiation Equation to the Hudson-Orrok Formula and to the Wohlenberg Formula.* A graphical comparison of the results obtained by the use of the Hudson-Orrok formula and the Wohlenberg method with the results obtained by the modified radiation equation is shown in Fig. 18 for the clean furnace condition.

It is to be noted that the radiation predicted by means of the Wohlenberg method is greater than that computed from the measured radiation intensities. Also, the total of radiation and convection (Wohlenberg method) is considerably lower than the total indicated by the Hudson-Orrok formula.

For one of the boiler tests (clean furnace) the radiation term in the Wohlenberg heat-balance equation has been made to agree with the measured radiation intensity. The result has been to

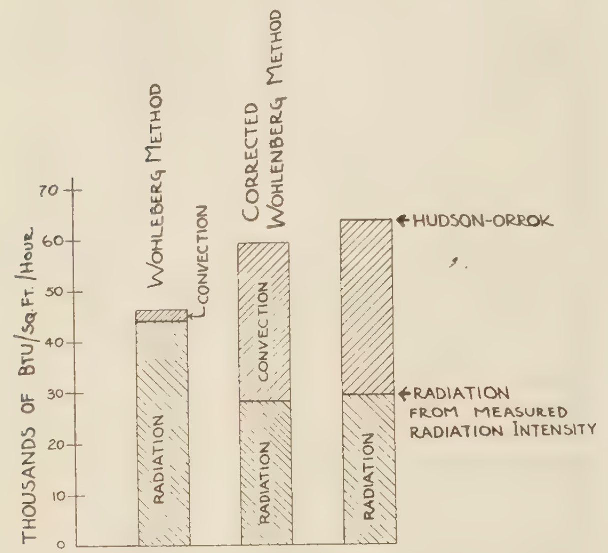


Fig. 19 Effect of Correction to the Wohlenberg Method (Boiler test No. 17.)

reduce the mean flame temperature from 2360 F to 2116 F, and thus to reduce the computed heat capacity of the gases leaving the furnace. To satisfy the heat-balance equation the convection term is increased. This change in the convection term which corresponds to the modification of the radiation term in the computations for boiler test No. 17 is shown in Fig. 19.

For this test, when the radiation term was made to agree with the measured radiation intensities, the convection term was increased, with the result that the total radiation and convection as computed from the Wohlenberg method is seen to be in close agreement with the value computed by the Hudson-Orrok formula.

*Summary.* In view of the additional data Equations [3], [4], and [5] (the tentative radiation equations) have been modified. The modified equations are:

Radiation intensity

$$I = \frac{0.5 + 1.1D}{1 + (A\sqrt{C_r}/27)} C_r U \ldots\ldots\ldots\ldots [15]$$

Rate of heat transfer by radiation

$$X_r = \frac{0.872\,(0.5 + 1.1D)\,(1 - 0.8D)}{1 + (A\sqrt{C_r}/27)} C_r U \ldots\ldots [14]$$

## Discussion

W. J. Wohlenberg.[4] It has been assumed by the authors that radiation-intensity measurements by themselves, as taken at different points on the walls of the furnace, will yield sufficient data with which to determine the energy absorbed by the water and steam from the furnace cavity. Let us consider what actually occurs at a square foot of cold surface covered by a dirty layer. In this case the specific rate of energy absorption at the surface is equal to the rate of thermal conduction through the dirty layer in front of the surface. The rate of thermal conduction through the surface is equal to the radiation intensity on the front side of the dirty layer minus the reradiation from the front of this layer to other parts of the furnace cavity. The authors of this paper have actually measured only one of the quantities involved, that is, the radiation intensity. They have then made a very rough estimate of the dirtiness condition of the surface, following which, on the basis of their assumption, they have applied the Hudson formula as adapted by Orrok for the purpose of arriving at the actual energy absorption. Thus, they have arrived at the relation between radiation intensity and the energy absorbed purely on the basis of an assumption, which may or may not be reasonably close to the truth.

It appears to the writer, however, that before any such assumption could be made it would be necessary to calibrate the radiation calorimeter with respect to the furnace cavity rather than with respect to a special black-body absorber. In general, this could be done in one of two ways: (1) If, in conjunction with the measurements of radiation intensity, the temperatures of the gases as they escape from the furnace cavity were ascertained by means of a suction thermocouple, then the actual heat absorbed from the gases could have been determined by means of a heat balance. This could have been related to the radiation intensities as measured by means of the calorimeter; (2) if, in conjunction with measurements of radiation intensities by means of the calorimeter, it were possible to measure the actual energy as heat which was absorbed by the water and steam circulating through tubes at all furnace walls, the latter quantity could have been related directly to the values of radiation intensity. Of course, on the furnace in question this method could not have been employed because some and probably all of the tubes at the furnace walls were connected in the boiler circulation and could not have been isolated without very great expense. Since this is the usual state of affairs in this respect, there are only a few boilers in the United States in which this method could be employed.

It may be said in general that the radiation-intensity method as used by the authors is not fundamentally new, as it has been used before under the name of thermal probe. This device usually consists of a flat-faced hollow steel block through which water is circulated. The heat absorbed by the circulating water is found by measuring its weight per unit time and its initial and final temperatures. The measurement is thus translated directly into Btu absorbed per unit of surface of the thermal probe. But this is exactly what the authors have done except that in the translation they have gone one step further, stating the result as radiation intensity.

Mullikin, in the course of his field work[5] on measurements of heat absorption in furnace cavities, at one stage of the development of the experimental work, attempted to use the thermal probe. He found that he could place little reliance on the results because of the (1) limitation as to number and location of openings which may be made in the furnace wall, (2) difficulty of operating more than one thermal probe at the same time, (3) lag in responsivity during the time intervals during which the furnace conditions change, (4) impossibility of having the same amount of slag on the thermal probe as existed on the furnace tubes, and (5) possibility of considerable error due to peculiar

[4] Professor of Mechanical Engineering, Sheffield Scientific School, Yale University, New Haven, Conn. Mem. A.S.M.E.

[5] Dissertation presented for degree of Ph.D., Department of Mechanical Engineering, Yale University, June, 1934, parts of which were presented at the Annual Meeting of the A.S.M.E., Dec., 2–6, 1935.

local conditions. Mullikin, of course, was using this device in order to obtain auxiliary information in a test the main object of which was to measure the temperatures of the gases as they left the furnace cavity. The latter measurements were made by the suction-type thermocouple. In view of all of this it seems quite apparent that it may be necessary to have a calibration of the radiation calorimeter not only for each type of furnace in which it is used but possibly also with respect to the positions in which it is located in a particular type of furnace.

For the reasons advanced in this discussion, the report as it stands seems to be incomplete. If the authors could take the additional measurements suggested and then submit a report in which the radiation calorimeter has been calibrated for the furnace cavity, it would be more convincing. This means the measurement of the gas temperature as the gas escapes from the furnace cavity, preferably by suction-type thermocouples. After this is done, the relationship between the heat-absorption and radiation-intensity measurements will be established for the particular furnace on which they are working. Thus, the calibration of the instruments with respect to the furnace would suffice even in this case to cover a wide range of operating conditions. It seems to the writer that the investigation must be made from this point of view before confidence can be placed in the results of the method.

Ralph A. Sherman.[6] This paper presents the results of an obviously extended investigation that has required a great deal of painstaking work. Several questions as to the apparatus used and the conclusions reached occur to the writer.

The radiation calorimeter used may have functioned very well, but one wonders why a thermopile was not used. The thermopile is much simpler, more portable, requires but one reading, the emf output, and attains its full output within a few seconds. If a thermopile had been used, a sylvite or rock-salt window, or no window, could have been used at the face of the absorber. This would have obviated what appears, at first glance, to be a fault with the authors' apparatus, the use of a quartz window. Quartz is opaque beyond about $4\mu$ and a considerable part of the radiation must never have penetrated the window. As, however, the water was in contact with the window, its transparency was of little or no moment and served only as a thermal insulator between the absorption chamber and the front cooling ring. From this viewpoint it would appear that any glass would have served as well as fused quartz.

The effective emissivity of the calorimeter is surprisingly low; as indicated by Equation [2] from Fig. 5, it is only 46.4 per cent. The quartz plate might have been expected to have had a higher emissivity; probably this is partly accounted for by the conduction loss to the front cooling ring. The calibration curve is a good straight line over the range shown, but this is very short in terms of temperature of the radiating source. The range of 35,000 to 60,000 Btu per sq ft per hr represents a range of only 300 F, from 1650 to 1950 F. As Table 1 shows measured radiation intensities of 12,000 to 107,000 Btu per sq ft per hr, considerable extrapolation must have been done. The propriety of this is questionable in view of the low effective emissivity over the range of calibration, as this may not have been constant beyond those limits.

The authors have properly stressed the importance of the condition of the water-cooled surfaces in the furnace with regard to the amount of slag and ash accumulation, which is not considered in either the Wohlenberg or Hudson-Orrok formulas. They show clearly in Fig. 10 how the measured radiation intensity increases as the surfaces become dirty, but in the original paper in their extensions of these data in Equations [4], [5], and [6] to arrive at a modified Hudson-Orrok formula to include the effect of dirtiness, the dirtiness factor $D$ appeared in the numerator which meant that as the tubes became covered with slag the amount of heat that they absorbed increased.

In the additional data given at the time of presentation of the paper[7] they have corrected this and show in Figs. 16 and 17 that the total heat transfer in the furnace decreases as the exposed surfaces become dirty. The authors maintain, however, that the radiation attains a maximum with a dirtiness factor of 0.4 to 0.5, which seems inconsistent to the writer.

The results presented in the paper are valuable as they are the most comprehensive measurements of radiation in boiler furnaces that have been presented to the Society. They show for the first time the effect of slagging of radiant surfaces and also indicate that the convection factor is more important than it has previously been considered to be.

### Authors' Closure

Prof. W. J. Wohlenberg's discussion was written without personal knowledge of the additional experimental work presented in the addenda. His criticism of the estimation of the actual radiation absorption was justified. However, the revised Equation [14] is based upon actual measured absorption rates. The authors are not confident that greater accuracy can be obtained in the calibration of the instrument by calibrating it in the furnace by measuring the gas temperature at the furnace outlet and then computing the theoretical condition in the furnace as suggested by Professor Wohlenberg. The authors are of the opinion that it is only necessary to indicate that velocity, temperature, and gas analysis traverses at the furnace outlet are required for accuracy by this method. The authors believe that the problem of furnace radiation will never be solved with scientific accuracy because of the multitude of experimental difficulties. Even if absolute results could be obtained accurately, could these results be applied with the same accuracy in a furnace where the temperatures and heat flows are continually changing?

Experimental results from isolated tubes in a furnace are extremely valuable, but for the principal topic presented in this paper, the convection effects and the radiation effects would require separation. The experimental evidence given in the paper would indicate that the net radiation absorbed as calculated by the Wohlenberg method is too large, while the convection component is too small as computed by the same method.

R. A. Sherman justly criticizes the form of Equations [5] and [6] (the tentative equations for heat absorption), since these equations would indicate that the net heat absorbed by radiation by the waterwalls would increase indefinitely with dirtiness. These relations have been revised in the light of the additional experimental work noted in the addenda, resulting in Equation [14].

Mr. Sherman's query as to why a calorimeter was used instead of a thermopile may be answered by the fact that originally it was believed the protective cooling of an instrument of the type used would be more satisfactory.

Many steps were taken before the present instrument was finally developed. L. P. Meade[8] is primarily responsible for the design of the present instrument. A rock-salt window was used initially because of the high transparency. However, Meade found that due to deterioration of the surface of the rock-salt, protective coverings of a special transparent lacquer were re-

[6] Fuel Engineer, Battelle Memorial Institute, Columbus, Ohio. Mem. A.S.M.E.

[7] See authors' addenda, which includes these additional data.

[8] "An Instrument for the Measurement of Radiant Energy in Boiler Furnaces," by L. P. Meade, a thesis presented in partial requirement for the Master's degree, University of Iowa.

quired. The final lacquered rock-salt window had a lower transmission than fused quartz and therefore the latter material was used because of its low coefficient of expansion.

The instrument was calibrated[9] for intensities from 12,000 to 50,000 Btu per sq ft per hr, although this is not indicated by the series of tests shown in Fig. 5 of the paper. The criticism of the low range of calibration is justified. Calibrations at higher intensities were not possible with the means at the author's disposal. The error due to the absorption bands of the quartz has been mostly eliminated by calibrating the instrument against a black-body absorber.

# The Loading and Friction of Thrust and Journal Bearings With Perfect Lubrication[1]

Ira A. Terry.[2] Mr. Howarth's paper presents information and data in such a form that it will unquestionably prove very useful to designing engineers in readily applying it to bearing design. As suggested by the author in Appendix B, it is not generally practical to apply the optimum conditions of pressures and journal diameters to commercial machines. It is customary to use standard bearing sizes with standard clearances and suitable manufacturing tolerances over quite a range of speeds and loadings in order to simplify as much as possible manufacturing operations. The wide range which must be covered by an individual bearing may not be conducive at all points to optimum conditions of lubrication. However, an understanding of the optimum conditions, together with the results it is possible to obtain, can be used very advantageously in laying out a line of bearings to fit fairly close to the most desirable dimensions, and further permits the careful study of special cases where lubrication problems may be rather severe.

The bearing losses in electrical machines are relatively unimportant in so far as machine efficiencies are concerned because of their small magnitude in comparison with other losses. Consequently, the main purpose of having fairly accurate data on which to base loss calculations is associated primarily with methods of cooling or otherwise dissipating the loss without excessive temperatures. Several years ago a series of tests was made to determine the coefficient of friction for two types of thrust bearings up to 42 in. outside diameter and for journal bearings up to 15 in. diameter. These tests involved pressures from 50 to 800 lb per sq in. and velocities from 400 to 10,000 fpm. Oil having a Saybolt viscosity of 250 sec at 40 C was used in tests. The room temperature was maintained constant at 30 C. By this means the equivalent of expected operating conditions was duplicated as close as possible, i.e., standard bearings may be applied throughout a very wide range of speeds and loads, and about the only constants involved are the kind of oil and the room temperature, both of which are specified by operating instructions for electrical machines. Since operating temperatures vary greatly under such conditions, the actual viscosity of the oil in the oil film will also vary greatly.

The test data were analyzed to obtain as simple an empirical formula as possible for calculating with a log-log slide rule the approximate bearing loss for both journal and thrust bearings. To allow for operating contingencies of lower room temperature, imperfect alignment, and finish imperfections, the formula was adjusted to give results 15 to 20 per cent higher. This formula is

$$\text{hp} = \frac{4\,AP^{0.4}}{10{,}000}\,\frac{(Nd)^{1.2}}{1000} \qquad [1]$$

where $A$ is the net area, sq in.; $P$ is the pressure on the net area, lb per sq in.; $N$ is the speed, rpm; and $d$ is the average bearing diameter, in.

An expression for the coefficient of friction will then be

$$\lambda = \frac{0.05}{P^{0.6}}\,\frac{(Nd)^{0.2}}{1000} \qquad [2]$$

These formulas, although not dimensionally correct, have been checked from time to time with test data on different types of thrust bearings and different proportions of journal bearings, including test data published in the technical press, and have been found to agree fairly satisfactorily with observations even when extrapolated to larger sizes than were included in the original tests. It is to be observed that the equations in respect to dimensions are importantly different from those presented by Mr. Howarth. Based upon Mr. Howarth's equation for coefficient of friction, the horsepower will vary as the 0.5 power of the pressure and as the 1.5 power of the average velocity, whereas in formula [1] of this discussion, the horsepower varies as the 0.4 power of the pressure and the 1.2 power of the average velocity. The length factor $l$ does not appear in formula [1] of this discussion although the manner in which $k$ varies with respect to $l$ in Mr. Howarth's formula for $\lambda$ on page 178 is such that the two effects practically offset each other.

TABLE 1 COMPARISON OF POWER LOSSES CALCULATED BY DIFFERENT FORMULAS

| Power loss, hp at 100 rpm: From Howarth's Table 2 | From Terry's test data and formula [1] |
|---|---|
| 0.0128 | 0.0162 |
| 0.0220 | 0.0293 |
| 0.0350 | 0.0477 |
| 0.0522 | 0.0735 |
| 0.0744 | 0.107 |
| 0.118 | 0.177 |
| 0.176 | 0.269 |
| 0.344 | 0.55 |
| 0.501 | 0.82 |
| 0.944 | 1.60 |
| 1.59 | 2.82 |
| 2.49 | 4.54 |
| 3.66 | 6.82 |
| 5.17 | 9.9 |
| 9.30 | 18.5 |
| 15.2 | 31.0 |
| 23.2 | 48.7 |
| 39.7 | 87.0 |

Obviously, formulas so widely different dimensionally cannot check over a range of sizes and speeds. Table 1 of this discussion compares the power losses at 100 rpm given by Mr. Howarth in his Table 2 with the corresponding point calculated from the writer's test data by formula [1] of this discussion. In this comparison, it should be observed that an essential difference between the bearing tested by the writer and the bearing described in Mr. Howarth's Table 2, is that the ratio $l/b$ was much smaller for the tested bearing than it was for the bearing described in the author's Table 2; therefore, the test results should be expected to be somewhat higher. At greater values of the pressure within the oil film $P$ and the relative velocity of the bearing surfaces $U$, the agreement would be better, except for very high values, in which case formula [1] of this discussion would show lower results than those given by the author.

In connection with the design of bearings and optimum conditions of lubrication, Mr. Howarth's last sentence of the first paragraph under "Film Thickness," page 183, is very pertinent. The third item of that sentence, relative to the possibility of the

[9] "Radiation in Steam Boiler Furnaces," by C. F. Schmarje, a thesis presented in partial requirement for an advanced degree, University of Iowa.

[1] Published as paper MSP-57-2, by H. A. S. Howarth, in the May, 1935, issue of the A.S.M.E. Transactions.

[2] Motor and Generator Engineering Department, General Electric Company, Schenectady, N. Y.

l film being required to pass foreign matter without serious in- ıry to the bearing surfaces, in general dictates shorter bearing- gment lengths in a circumferential direction than may be de- rable from a purely optimum condition of lubrication asso- ated with a minimum oil-film thickness. From this standpoint, bearing having a shorter length $l$ seems to be the best choice of sign since the length over which a foreign particle may be re- ıired to travel between successive oil grooves is shorter and con- quently injurious heating as a result of it is less liable to occur.

In the second paragraph of Mr. Howarth's paper under "The oading and Friction of Journal Bearings," page 176, the author scusses an assumption made by several investigators that the efficient of viscosity $\mu$ is assumed to have a constant mean alue throughout the film. In attempting to determine what ıis mean viscosity might be, most investigators have taken an ithmetical mean between the inlet and outlet temperature. bservations which have been made on bearings having a sta- onary plate made of glass may be of interest. Three types of earings were tested: (1) pivoted shoe, (2) parallel plate flexibly ıpported, and (3) taper land. All three of these bearings showed ı inherent similar characteristic that each oil groove has a one- xth to one-fifth scavenging effect. Therefore, a maximum of oout five-sixths of the oil in the oil film in one segment passes on the next segment where the oil film, of course, becomes re- enished by the addition of one-sixth new oil and then one- xth of the combination is dropped at the following groove. he observations to determine the scavenging action were made injecting coloring matter into the oil film and observing the sults as the bearing surfaces moved relative to each other. lthough the value may not be expected to represent exactly the nount of scavenging, and furthermore different conditions of st set-ups might lead to somewhat different results, still an in- cation of such a small amount of scavenging at each oil groove eans that careful thought must be given to the actual tempera- re occurring inside an oil film before deciding upon the mini- um oil-film thickness, and upon the average value of viscosity hich may be used to represent losses.

The author discusses under various headings on pages 182 and 3 formulas which may be applied to the solution of problems sociated with forced-oil starting of bearings. There are many stances in the practical application of journal bearings where gh-pressure oil pumps are connected to the bearings in order to t the shaft on an oil film previous to starting and thereby reduce e in-rush required to start an electric motor to a value which a rticular distribution system can stand without objectionable cker. By this means the coefficient of static friction is elimi- ted and there is obtained an extremely small starting friction that the torque required to start the motor is only that as- ciated with the windage loss; and a reasonable length of time required to bring the machine to speed.

Mr. Howarth's formulas 19 to 26 check fairly well with some sults observed on bearings equipped for forced-oil starting, and only if, it is possible to determine the thickness of the film $h$ and the viscosity of the oil $\mu$. These are extremely ficult to determine.

Fig. 8 in the paper shows the type of construction frequently ıployed for forcing oil in between a bearing and a journal. By plying a pressure $P_1$ at the entrance to the bearing approxi- tely equal to two or three times the mean bearing pressure sulting from the load, it is found that an apparent lifting force 5 per cent is sufficient to cause the formation of an oil film be- een the surfaces. By this apparent lifting force is meant the oduct of the pressure $P_1$ by the area represented in the circle radius $r_1$. The action of this forced oil is to instigate a slight l of the journal to one side or the other of a bearing. After s roll has taken place, oil can proceed out from the inlet hole at a fairly rapid rate causing the lift of the bearing. In the case of flat plates, a similar apparent lifting force produces a slight deformation of the plates adjacent to the oil hole that is sufficient to make the oil spread out from the hole in a manner similar to the disturbances caused by a rock dropped in a calm pond.

S. J. Needs.[3] Mr. Howarth has pointed out that optimum conditions in bearings are brought about by the geometrical form

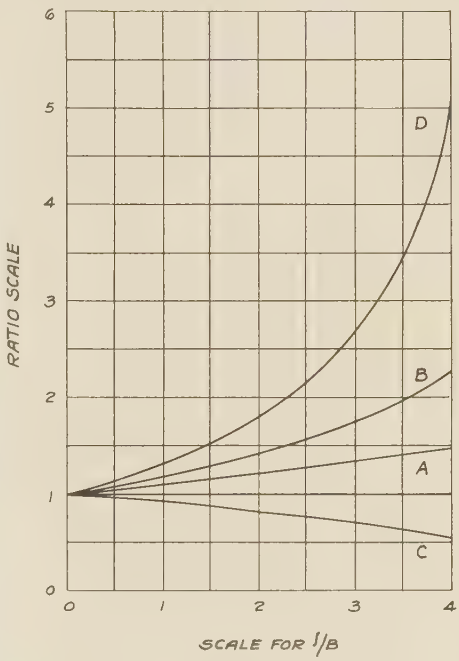


Fig. 1

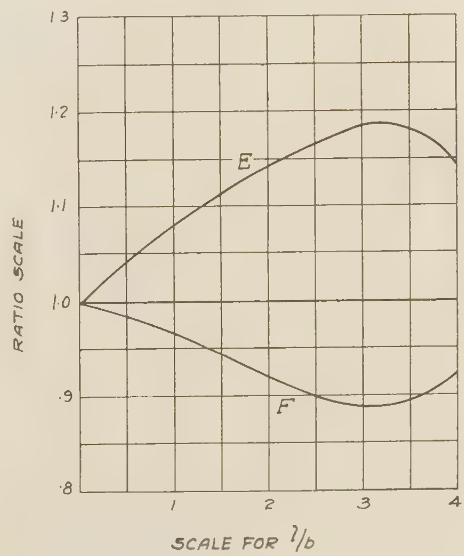


Fig. 2

of the oil film. Any bearing having a fluid film and operating with a given load and speed will have some minimum film thick-

[3] Research Engineer, Kingsbury Machine Works, Inc., Philadelphia, Pa. Mem. A.S.M.E.

ness $h_o$. For optimum load or friction conditions to exist, the film thickness at all points must bear a definite relation to the minimum film thickness. These relations have been tabulated in the paper by Dr. Kingsbury, referred to by Mr. Howarth and again are brought to attention in Mr. Howarth's present paper. They were calculated from theoretical considerations and refer to bearings of infinite width.

The investigation referred to by Mr. Howarth, which was undertaken by the writer, had for one of its objects, the determination of whether the film form found to be optimum at infinite width would also be optimum at all finite widths. As anticipated by Dr. Kingsbury, it was found that at finite widths, the optimum film forms were somewhat different from the optimum at infinite width. To date, only the 120-deg centrally supported clearance bearing has been investigated for this condition; although similar behavior may be expected in other types.

As the bearing is decreased from infinite to finite widths, the change in the optimum film form is due to the fact that best conditions are found at increasing eccentricities as the bearing becomes narrower. Hence, to obtain the best load and friction conditions for a given minimum film thickness, the relative radial clearance ($\eta/h_o$) must be increased as the width of the bearing is reduced. In Fig. 1 of this discussion, curves $A$ and $C$ show, respectively, the magnitude of the improvements in load capacity and minimum friction coefficient (above the values given by Dr. Kingsbury's charts and Mr. Howarth's present paper) that may be brought about by increasing the relative clearance and thus establishing optimum film forms at finite widths. Curve $B$ shows the required increase in relative clearance to bring about the improvements in load capacity shown by curve $A$, and curve $D$ shows the required increase in relative clearance necessary to bring about the improvements in minimum friction coefficient shown by curve $C$. The improvements are given as ratios by the vertical scale, the ratios being comparisons of the results given by Mr. Howarth's class-$C$ charts when used with the generally applicable side-leakage chart $KX$; and similar results as found by the writer. The former results are represented in Figs. 1 and 2 of this discussion, by unity, for all values of $l/b$, the latter results being represented by the curves. For example, let us consider a 120-deg centrally loaded bearing, the length in the direction of motion being the same as the width, or $l/b = 1.0$. From the class-$C$ tables given by Mr. Howarth, and his $KX$ chart, values for the maximum load capacity and minimum friction coefficient may be found and also the relative clearances necessary to bring these conditions about. From Fig. 1 of this discussion, we find from curve $B$ at $l/b = 1.0$, that if we increase the relative clearance for maximum load, as given by Mr. Howarth's paper, 1.185 times or 18.5 per cent, the film form will become optimum and the load capacity will be increased 1.10 times or 10 per cent, as shown by curve $A$ in Fig. 1 of this discussion. This increase in relative clearance permits the eccentricity to increase from $c = 0.4688$, the optimum value at infinite width, to $c = 0.552$, the optimum value for $l/b = 1.0$. Similarly, curve $C$ shows a 7.3 per cent drop in minimum friction coefficient by increasing the relative clearance 31 per cent as shown by curve $D$. Here, the increase in clearance will permit the eccentricity to increase from $c = 0.4904$, the optimum value at infinite width, to $c = 0.612$, the optimum value at $l/b = 1.0$.

From Fig. 1 of this discussion it is apparent that the gains in load capacity and in minimum friction coefficient are less in percentage than the necessary increases in relative clearance to bring them about. Since most bearings are wider than the square proportions, falling between $l/b = 0.5$ and $l/b = 1.0$, the advantages to be gained in load capacity and minimum friction coefficient are negligible, as has been pointed out by Mr. Howarth. Should the bearing be relatively narrow, however, appreciable advantages in load capacity and reduced friction may be obtained by increasing the relative clearance to the amount required for the formation of the optimum film form. The narrower the bearing the greater the advantages and the greater the required increase in clearance, the minimum film thickness remaining constant for all $l/b$ ratios.

In some cases large clearances may be undesirable since they increase the difference between the shaft positions when running and at rest, and cause higher concentration of pressures at starting and stopping. Therefore, if we maintain at all finite widths the relative clearances found to be optimum at infinite width, the objection of relatively large clearances is overcome but making it impossible to establish the optimum film form in practical bearings. From this point of view the results, obtained by using the class-$C$ table and the side-leakage chart $KX$ in Mr. Howarth's paper, are found to be in close agreement with the results of the investigation of 120-deg centrally loaded bearings mentioned in the second paragraph of the writer's discussion. The comparison is made in Fig. 2. Unity on the ratio scale again represents the values given by Mr. Howarth's class-$C$ table used with his chart $KX$. Curve $E$ gives the comparative results for load capacity for constant eccentricity $c = 0.4688$ and constant relative clearance $\eta/h_o = 1.883$. Curve $F$ gives the comparative results for friction coefficient for constant eccentricity $c = 0.4904$ and constant relative clearance $\eta/h_o = 1.962$.

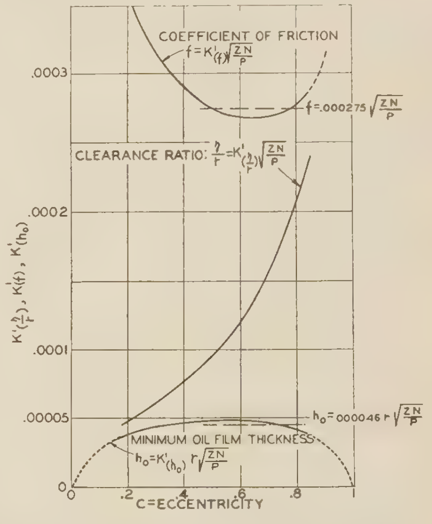


Fig. 3 Characteristics of 120-Deg Central Partial Journal Bearing With Length Equal to Diameter

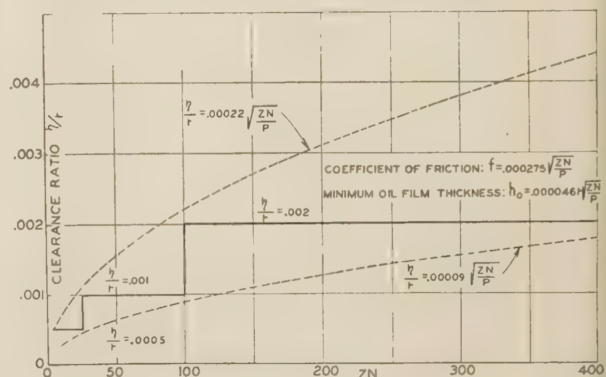


Fig. 4 Clearance Ratio for Optimum Condition of 120-Deg Clearance Bearing

L. M. Tichvinsky[4] and R. Baudry.[5] With reference to the author's chart Fig. 13, the writers wish to mention the practical aspect of the clearance ratio $\eta/r$ in the region of optimum condition. The writers made an analysis for the case of 360-deg and 90-deg journal bearings and showed, in a paper, "Performance of Large Journal Bearings," by R. Baudry and L. M. Tichvinsky, presented at the Annual Meeting, 1934, that the ratio $\eta/r$ may vary considerably in the region of optimum condition. The case of a 120-deg clearance bearing was considered in Mr. Baudry's discussion of S. J. Need's paper,[6] and some of the observations of that discussion are repeated here. In Fig. 3 of this discussion, the bearing eccentricity $c$ is plotted as abscissas ranging from 0 to 1, thus covering the complete operation of the bearing performance. The ordinates of this figure are the values of clearance ratio, minimum oil thickness, and coefficient of friction.

It is seen from Fig. 3 of this discussion that for a variation of the clearance ratio from less than 0.001 in. per in. to more than 0.002 in. per in., the coefficient of friction will vary only plus or minus 2 per cent of the mean value shown on the curve. The variation of the oil-film thickness is of the same order.

On Fig. 4 of this discussion (plotted from Fig. 3) is shown the clearance ratio which will give the optimum condition for various values of $ZN/P$. It is seen that the clearance ratio remains constant for a rather large variation of $ZN/P$. Therefore, it is possible to use a constant clearance ratio over a large range of bearing operations and still operate near optimum conditions of the bearing performance. It is interesting to note that this corresponds with clearances determined by experiments and used on Westinghouse bearings.

Thus, for example, it is the Westinghouse practice to use a clearance of 0.002 in. per in. for high-speed turbogenerators operating with values of $Zn/P$ varying from 100 to 400. For former slow-speed power bearings with a 120-deg angle and values of $ZN/P$ below 100, a clearance ratio of 0.001 in. per in. was used.

G. B. Karelitz.[7] Some time ago the writer offered charts for the determination of the minimum oil-film thickness in a central journal bearing.[8] The analysis was based on premises slightly different from the author's. The examples given in the paper, were worked out on the basis of the charts in the writer's paper the comparative results being given in Table 2 of this discussion.

TABLE 2 COMPARISON OF OIL-FILM THICKNESSES OBTAINED BY KARELITZ AND HOWARTH METHODS

| Example no. from Howarth's paper | Oil-film thickness, in. Howarth | Karelitz |
|---|---|---|
| 1 | 0.0030 | 0.0032 |
| 3 | 0.0048 | 0.0045 |
| 4a | 0.0017 | 0.0018 |
| 4b | 0.0029 | 0.0025 |

For practical purposes, the results in Table 2 are sufficiently close, while the treatment in the writer's paper is very much simpler. This suggests that the rigorous treatment presented in Mr. Howarth's graphs might be simplified without impairing the value for practical designers.

Concerning the friction in journal bearings, it is the writer's contention that the total amount of friction in oil-ring bearings or in power bearings with forced feed is close to the friction in a 360-deg tubular bearing under the same conditions of load, speed, and clearance. Admittedly, this field is still open for investigation but as yet little work has been done because of the difficulty involved in making the experiments. It must be kept in mind that the coefficients of friction given in the paper refer only to the friction in the active oil film. The total losses in bearings can be determined closer by the chart given by McKee.[9]

Example 7 of the paper, dealing with a 360-deg bearing, gives the coefficient of friction $\lambda = 0.0080$ compared with McKee's figure $\lambda = 0.0098$. The losses in the oil film of Mr. Howarth's example 1 given as 6.6 hp are, however, much lower than McKee's figure of 16 hp, which actually would obtain in a normal power bearing of a size required for the load and speed stipulated in the problem. It is hoped that investigators in the field of bearing mechanism will be stimulated by Mr. Howarth's paper to investigate experimentally and present their findings on friction in bearings with perfect lubrication.

### Author's Closure

The author appreciates the valuable discussions that have been offered by I. A. Terry, S. J. Needs, L. M. Tichvinsky, R. Baudry, and G. B. Karelitz, and will endeavor to answer the questions they have raised and to add comments that may clarify the points involved.

Although bearing losses may be, as Mr. Terry has said, relatively unimportant in the matter of overall efficiency of electrical machinery, the author would like to point out that power loss in bearings is not by any means insignificant in large high-speed hydroelectric units, such as those being built for Boulder Dam.

At a normal speed of 180 rpm the friction loss in a Kingsbury thrust bearing for the Boulder units would be about 200 hp when carrying a load of 1,750,000 lb. Surely it should be important to the engineer and to his client, the investor, whether such a machine be equipped with a bearing wasting 200 hp or with one wasting 250 or 300 hp or more. The cost of the hydroelectric installation may amount to $200 per horsepower developed by the turbine. If only 50 hp could be saved in thrust-bearing loss per machine, the investment value of it would be $10,000, which is approximately the price of a thrust bearing for such a machine.

That power losses may vary over even a wider range than this for different types of bearings, should be evident from Fig. 12 in Appendix $D$ of the paper. It is shown in this figure that deviations from optimum in the design of thrust bearings of the flat-wedge type may increase the friction as much as five or more times the optimum value. Such increases in power loss are accompanied by corresponding decreases in film thickness and margin of safety.

The tests to which Mr. Terry refers are of such importance as to warrant their complete description in an engineering paper so that the conclusions drawn from them could be examined critically. It is quite probable that the formulas proposed by Mr. Terry could then be shown to represent design variations or experimental abnormalities rather than real differences between theory and practice.

With regard to the best circumferential length for the segments of a Kingsbury thrust bearing, the longer they are, the thicker will be the films produced by them, other factors being unchanged. Conversely, the shorter they are, the thinner the film and the higher the friction. A careful study of this matter, taking into account the side leakage of oil from the films, shows that the proportions used by Dr. Kingsbury are very close to the optimum.

[4] Westinghouse Research Laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

[5] Power Engineering Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

[6] Discussion by R. Baudry of "Effects of Side Leakage in 120-Degree Centrally Supported Journal Bearings," by S. J. Needs, A.S.M.E. Trans., vol. 57, no. 3, April, 1935, p. 136.

[7] Professor of Mechanical Engineering, Columbia University, New York, N. Y. Mem. A.S.M.E.

[8] "Performance of Oil-Ring Bearings," by G. B. Karelitz, Trans. A.S.M.E., vol. 52, part 1, 1930, paper APM-52-5, pp. 57–70.

[9] "Friction of Journal Bearings as Influenced by Clearance and Length," by S. A. McKee and T. R. McKee, Trans. A.S.M.E., vol. 51, part 1, 1929, paper APM-51-15, pp. 161–170.

Mr. Terry's discussion of the scavenging effect of oil in a groove is very valuable indeed and covers a point that is rarely mentioned. It is very desirable that this matter be investigated fully and that its importance be emphasized. The author hopes that Mr. Terry will find time to cover this fully in a paper before the Society.

Mr. Needs has clarified the advantages to be gained when designing 120-deg centrally loaded bearings of finite width, with reference to his special investigation of that type.

Messrs. Tichvinsky and Baudry have again pointed out the important fact that deviations from optimum conditions may be considerable without encountering serious increase of friction. One must not forget, however, that by proper choice of viscosity of lubricant, a bearing can be made to operate under optimum conditions. Hence, the real criterion of design proves again to be the minimum film thickness that is considered permissible.

The question of minimum film thickness is discussed by Mr. Karelitz who shows that the results of the author's rigorous analysis yield approximately the same values for the examples as do his more approximate method. It is the belief of the author that the more rigorous the analysis the wider the range over which it may be relied upon.

The author has purposely segregated the pressure film friction of journal bearings so that it may be studied separately. This should lead to the improvement of constructions that generate useless friction. Some idea of the friction wasted by a close-fitting cap can be obtained by means of Equation [5] in Appendix $C$ of the paper.

The work of McKee to which Karelitz refers is a valuable contribution to the solution of this problem of total friction in bearings of various widths, wholly surrounding their journals. Checking the figure 16 hp given by Karelitz yields a value of 12.2 hp from McKee's tests. Adding the influence of the cap to the film loss in example 1 of Appendix $B$ of the paper yields a total of 11.6 hp, or 6.6 hp for the pressure film plus 5.0 hp for the cap. This checks very well with McKee's 12.2 hp. The reason for the closeness of the figures for the film loss of 6.6 hp, and the cap loss of 5.0 hp, is due to the assumption that the cap angle is 360 deg less the film angle. This ignores the influence of oil channels, as was done by McKee. It is probable, however, that the loss in such a high-speed bearing, with a suitably wide oil channel on each side, would be about 9 hp instead of 11.6 hp.

# The Division of Load Among Generating Units for Minimum Cost[1]

C. Harold Berry.[2] Mr. Mulligan states that "The first publication of the basic principles . . . . except for the simplest case where the input curves are all straight lines, was by F. H. Rogers in 1924." This statement is somewhat of a surprise, because the writer has known the method described by Mr. Mulligan to be in use for nearly 20 years. The writer has in his possession prints of curves prepared by W. A. Hirt of The Detroit Edison Company, in June, 1919, showing the input of several steam turbines, the first derivative curves, and the resulting graphical table of load distribution for various combinations of units running, the operating units being run at such loads that the slopes of the input-output curves are equal. These particular blueprints have been kept merely as samples of the method, which in 1919 was the common practice of the Detroit company. The writer feels confident that expositions of the method must have been published earlier than 1919, but has been unable to locate anything earlier than the N.E.L.A. Proceedings of the 43rd Convention, May, 1920, where, on page 622, will be found a brief description of the method.

The writer believes that those who are concerned with the operation of power plants and systems have long known of this method of apportioning load among diverse units, and have regarded it as a useful general guide. On the other hand, the exigencies of daily operation often make strict adherence to any such scheme impracticable. Machines cannot profitably be started and stopped at short intervals. Large steam turbines require long warming-up periods. The need for a machine must be known somewhat in advance, and there must be in prospect a reasonably long running period to justify incurring the starting losses and subjecting the machine to the hazards associated with starting and stopping it. This, however, does not detract from the usefulness of the derivative method of distributing load, for, when it can be followed, there is no doubt that it yields the best attainable results.

Mr. Mulligan bases the validity of the method upon a graphical discussion of increments of input resulting from departures from the optimum load distribution. If the situation is subjected to a mathematical analysis, the proof becomes relatively simple, and, moreover, the seemingly anomalous behavior of machines with inflected input curves becomes clear.

Let us designate the aggregate plant or system input by $I$, the nput of each unit by $i_1, i_2, \ldots, i_n$, and the corresponding outputs by $O, o_1, o_2, \ldots, o_n$.

The aggregate system input is the sum of the inputs to the individual machines

$$I = i_1 + i_2 + \ldots + i_n \qquad [1]$$

If, through variations of load, the inputs to individual machines change, the increment of aggregate input is the sum of the individual increments. Since the relation of Equation [1] is linear, this may be written in terms of differentials.

$$dI = di_1 + di_2 + \ldots + di_n \qquad [2]$$

Now, for each individual machine, the input is a function of the output of that machine, and of a number of other variables, such as initial steam pressure and temperature, exhaust pressure, water levels in head- and tailraces, and the like. Let these other variables be designated by $x, y, \ldots$ Then, for any single unit, the differential of input is

$$di = \frac{\partial i}{\partial o}\,do + \frac{\partial i}{\partial x}\,dx + \frac{\partial i}{\partial y}\,dy + \ldots \qquad [3]$$

But, for the purpose of studying the distribution of load for minimum aggregate input, it is properly assumed that the variables other than output are unchanging. Obviously, if exhaust pressure or hydraulic head is to vary, the plant input will vary entirely apart from any considerations of load distribution. Such variations must be ruled out for the purposes of this study. If this be done, the differentials $dx, dy, \ldots$ all become identically zero, and Equation [3] reduces to

$$di = \frac{\partial i}{\partial o}\,do \qquad [4]$$

Substitution of values typified by Equation [4] in Equation [2] gives

$$dI = \frac{\partial i_1}{\partial o_1}\,do_1 + \frac{\partial i_2}{\partial o_2}\,do_2 + \ldots + \frac{\partial i_n}{\partial o_n}\,do_n \qquad [5]$$

[1] Published as paper FSP-57-6, by J. E. Mulligan, in the April, 1935, issue of the A.S.M.E. Transactions.

[2] Gordon McKay Professor of Mechanical Engineering, the Graduate School of Engineering, Harvard University, Cambridge, Mass. Mem. A.S.M.E.

For the optimum distribution, the aggregate plant input $I$ has a stationary value, that is, its differential must vanish, or

$$dI = 0 = \frac{\partial i_1}{\partial o_1} do_1 + \frac{\partial i_2}{\partial o_2} do_2 + \ldots + \frac{\partial i_n}{\partial o_n} do_n \ldots\ldots [6]$$

In addition to this, we have another restriction. The problem is to find the optimum distribution of a given aggregate output. In other words, the aggregate output $O$ which is the sum of the individual unit outputs is to be constant. That is

$$dO = 0 = do_1 + do_2 + \ldots + do_n \ldots\ldots\ldots\ldots [7]$$

Equations [6] and [7] must both hold true for any set of values of the differentials $do_1, do_2, \ldots . do_n$, all but one of which are independent, and may be assigned any desired value. The necessary and sufficient condition for this is

$$\frac{\partial i_1}{\partial o_1} = \frac{\partial i_2}{\partial o_2} = \ldots = \frac{\partial i_n}{\partial o_n} \ldots\ldots\ldots\ldots\ldots [8]$$

Equation [8] states the condition under which the aggregate plant or system input will have a stationary value with respect to small variations in distribution. But this does not tell us whether this value will be a minimum or a maximum. Further criteria are needed to determine this question.

As in the case of a simple curve, the distinction between a maximum and a minimum is stated in terms of the second derivative. If the second derivative is positive, the point is a minimum; if it is negative, the point is a maximum.

In the present case, we are dealing with a quantity that depends upon numerous variables, and accordingly there are numerous second derivatives. The complete analysis of the situation is too extensive to give here, but a statement of the results can be made fairly concisely.

If the second derivatives of the individual unit input curves are all positive, then the distribution corresponding to Equation [8] provides a minimum value of the aggregate plant or system input.

If, on the other hand, some of the individual units have input curves with negative second derivatives, that is, input curves that are convex upward, then the relative magnitude of the positive and negative second derivatives may be such that the distribution set by Equation [8] provides a maximum plant or aggregate input. In the case of two units, the situation is simple. If both second derivatives are negative, or if one of them is negative and the other positive but smaller (so that their sum is negative), then the distribution for equal first derivatives will correspond with a maximum aggregate plant input, rather than with the minimum that we seek. This is the case discussed by Mr. Mulligan for inflected input curves. Beyond the point of inflection, both curves have a negative second derivative.

For the case of more than two units, the situation becomes too complex for brief statement. Involved relationships among the signs and magnitudes of all the possible second derivatives determine whether the distribution satisfying Equation [8] corresponds with a maximum, or a minimum, or is something analogous to the point in a saddle where the tangent plane is horizontal, but corresponds to neither maximum nor minimum.[3]

Mr. Mulligan has done good service in bringing this question once more to the fore, and in drawing attention to the necessity of considering the possibility of input-output curves that are convex upward. So far as the writer knows, this is a point that heretofore has not been discussed.

[3] "Advanced Calculus," by William F. Osgood, The Macmillan Company, New York, N. Y., 1929, p. 178; and "Lectures on the Theory of Functions of Real Variables," by James Pierpont, Ginn and Company, New York, N. Y., 1905, vol. 1, p. 326.

M. J. Steinberg.[4] It is generally recognized that correct load division is an important factor influencing the economic generation and transmission of electric energy. It is also generally recognized that correct load division can be obtained only

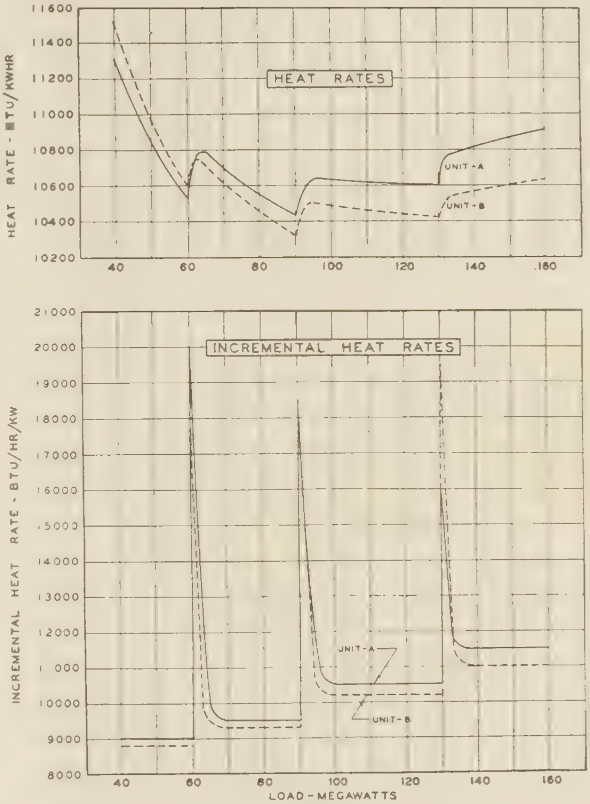


Fig. 1

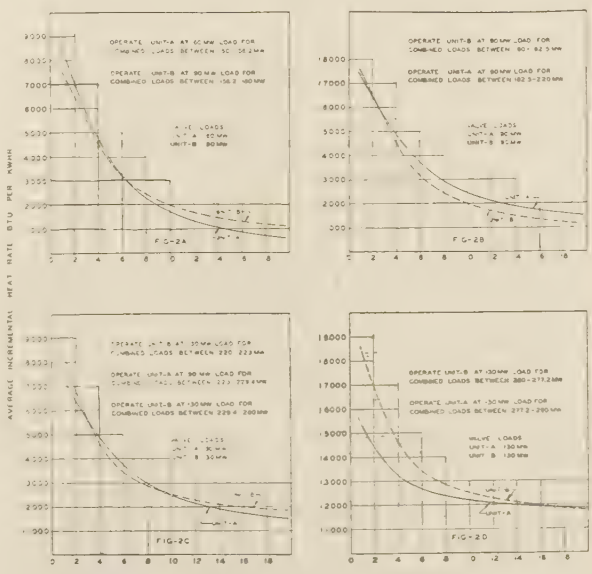


Fig. 2

[4] Assistant Engineer, Operating Department, Brooklyn Edison Company, Inc., New York, N. Y.

by the proper application of incremental rates. Since this subject is treated in Mr. Mulligan's paper from a purely theoretical point of view, a discussion of some of the practical aspects of the problem should be of interest.

The academic solution of load division problems cannot be justified at all times. This condition arises frequently in the turbine room in connection with load division among steam-turbine generators with characteristics similar to those illustrated by Fig. 6 of the paper. The curves shown in this figure are typical for modern multivalved steam turbines. At each load corresponding to maximum opening of a valve, there is a discontinuity in the incremental heat-rate curve followed by a sharp decrease in value over a relatively small range in load. Because of this latter characteristic, the proper division of load cannot be determined solely on the basis of the respective incremental heat rate curves.

By way of illustration and to permit a more detailed analysis of the procedure outlined in the paper, consider the curves of Figs. 1 and 2 of this discussion, which represent the performance characteristics of two units of the type under discussion. For any combined load between 80 and 150 megawatts, the proper division of load can be directly determined from the incremental

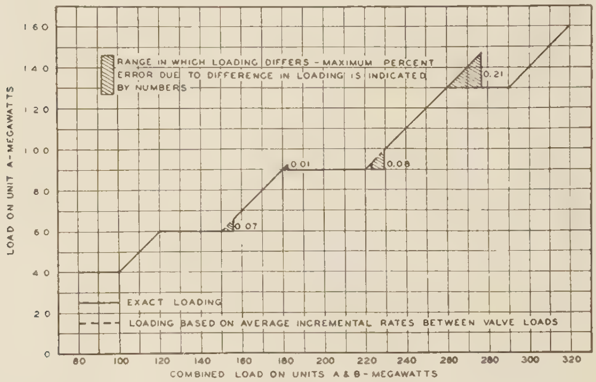


Fig. 3

heat rate curves of the writer's Fig. 1. For loads in excess of 150 megawatts, it becomes necessary to use the curves of Fig. 2 of this discussion. These show for each unit, the *average* incremental heat rate at which an increment of load in excess of any valve load can be supplied. If the division of load in the range from 150 to 180 megawatts be considered, then from the curves of Fig. 2*A*, it is seen that unit *A* should be operated at its valve load of 60 megawatts while unit *B* supplies the balance of load up to a combined load of 156.2 megawatts. If the combined load exceeds 156.2 megawatts, the load on unit *B* is first reduced to 90 megawatts, its valve load, and the balance supplied by unit *A*. Thus, the intersection of the two curves of Fig. 2*A* indicates, theoretically at least, the need of shifting load from unit *B* to unit *A* when the total load increases from 150 to a value in excess of 156.2 megawatts. Similar procedure is necessary in the other ranges of load, and for the two machines under discussion it was necessary to establish four sets of curves to determine the correct load division over the entire range of load. An exact solution, when more than two units of this type are involved, requires an excessive amount of time and labor which, experience has shown, may be considerably reduced without introducing more than a negligible error, by the use of average incremental rates. These are established by dividing the difference in successive inputs corresponding to the valve loads, by the corresponding differences in output. Thus, if the loads at which the valves are fully open and the corresponding inputs are known,

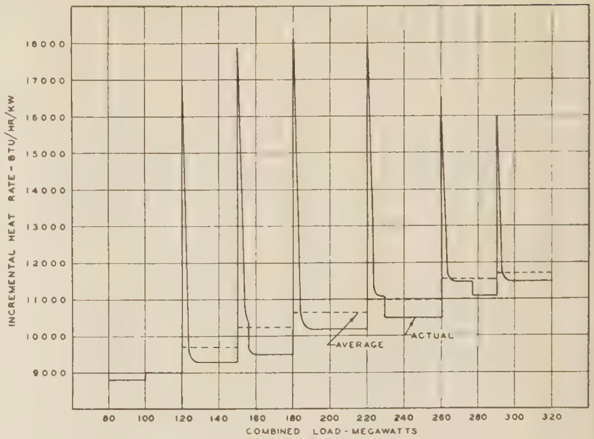


Fig. 4 Incremental Rates for Combined Operation

it becomes a relatively simple matter to calculate the average incremental rates and what is more important, determine the division of load without recourse to curves similar to those of Figs. 1 and 2 of this discussion.

A comparison between the two methods is illustrated by the writer's Fig. 3. The crosshatched areas correspond approximately to the ranges of load in which the discontinuities and the sharply decreasing values of the incremental rate curves occur, and represent but a very small portion of the entire range of load. The maximum per cent increase in input due to the variation in loading is indicated for each area, and it is obvious that they are of negligible magnitudes and well within the accuracy with which turbine-generator heat rate curves can normally be established.

In the case of steam-generating stations, load division in the turbine room represents but one phase of the problem. The boiler room must also be considered, the ultimate object being to establish the incremental rate curves for the station so as to permit the proper allocation of load among several stations. The academic solution as outlined in the paper, if not impossible, is surmounted by so many difficulties that it can rarely, if ever, be justified. Consider the curves of Fig. 4 of this discussion in which a comparison is shown between the actual and average incremental rate curves for the combined operation of the two units under discussion. With two or more stations equipped with turbines of this type, it should not take a great deal of imagination to visualize what an academic solution of the problem involves.

The paper also presents a criteria for dividing a load, which varies uniformly with time, among several generators, some which may be operating at fixed throttle or constant output during the period of uniformly increasing or decreasing load. The author recommends the use of an average input-output curve for the unit or units that absorb the variation in the system load, represented in Fig. 7 of the paper as $\bar{I}_2$. For the purpose of illustration the author has used input-output curves whose respective incremental rate curves are smooth, continuous and with incremental values that never decrease with increase in output. Curves of this type are characteristic of hydroelectric units; in the case of steam-turbine generators it is more likely that the incremental curves will be similar to those shown in Fig. 1 of this discussion or consist of a series of horizontal, step-like straight lines. The most economical load division among turbine-generators characterized by either or both of the latter, is obtained only when all but one unit are operating at fixed throttle or constant output, while the single unit absorbs any change in the

total load. Thus, in Fig. 3 of this discussion it will be noted that as the combined load increases, one of the two machines operates at a valve load, while the other supplies the increase in load, and this is true whether the load division is based on either the actual or average incremental rates. The use of average input-output curves when machines of these types only are involved, is obviously unwarranted.

It is recognized that in every system there probably exists equipment of early design and relatively low efficiency which is used for emergency or standby service under system peak-load conditions. Among steam-turbine generators under this classification there may be a limited number whose incremental curves have the characteristics of the curves shown in Fig. 7 of the paper. These units, when operating in conjunction with prime equipment, are usually maintained at some predetermined minimum output, irrespective of the variation of the total system load. They are seldom, if ever, used as regulating units so that under these conditions there is no need for the application of average input-output curves.

Notwithstanding the foregoing, an attempt was made to derive the average curve from an actual input-output curve. When the usual graphical methods were employed, it was found that the differences were too small to be capable of graphical determination. An equation was therefore fitted to the input-output curve and the differences computed mathematically. The differences between the two curves are shown in Fig. 5

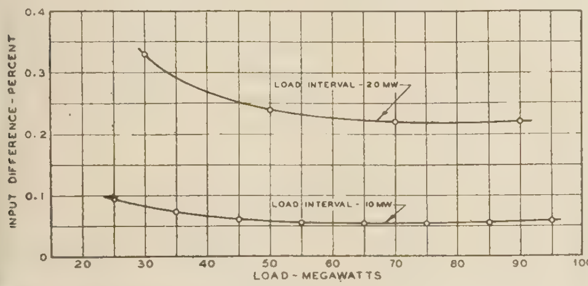


Fig. 5 Difference in Input Between Actual and Average Input-Output Curves

(Input-output curve data: $I = A + B + CL^2 + DL^3 + EL^4$ = turbine input, million Btu per hr; $L$ = generator load, megawatts; $A$ = 155; $B$ = 6.41; $C$ = 0.04; $D$ = — 170.7 × $10^{-6}$; and $E$ = 1.49 × $10^{-6}$.)

of this discussion. The input differences are a function of the curvature of the input-output curve and the magnitude of the load intervals for which the averages are obtained. On the basis of the analysis shown in Fig. 5, it is believed, that even in the case of hydroelectric units, there is a very limited field in which the application of the recommended average curve can be justified.

Another important factor which eliminates the need of using average input-output curves, is the fact that it is customary for station operators to be supplied with loading schedules which they are required to follow in loading the individual units.

Although the loads of all units cannot be adjusted continuously as the total load changes, adjustments can be made frequently enough so that any loss in efficiency from the failure to follow the schedules becomes a negligible quantity.

In conclusion, the author is to be congratulated for the manner in which the fundamental principles of load division have been presented. The use of graphical instead of mathematical analysis has been helpful in clarifying the subject matter. The application of incremental rates has been general in the field of power generation and transmission and they have been in use over a sufficiently long period to permit some interesting operating experience. It is believed that a meeting could be profitably devoted to a discussion of the practical aspects of the problem of load division, and it is hoped that this will be provided for in the near future.

L. J. Levert.[5] Mr. Mulligan admits that not all is well with increment rates. On many occasions he resorts to the use of total-input-output curves, due to theoretical limitations of increment rate curves. We, who have to operate the system, have to consider practical limitations as well. This fact makes us depend on the total-input-output curves even to a greater extent. Actually, we determine the most important points through the use of total-input-output curves and then fill in the space between with the assistance of increment rates. Even the use of total-input-output curves in preference to increment rates is no assurance that the most economical operation will result.

For the purpose of illustration, let us assume that we have a system where all equipment, including boilers and turbines, can be "plugged in and out" with the rapidity and ease of a telephone connection. The system used in this illustration consists of four 100,000, four 50,000, and four 25,000-kw units. The figures used for computing the heat consumption were based on the actual operating performance of the existing units.

The solid line in Fig. 6 of this discussion shows the operating sequence indicated for the use of input-output curves. The

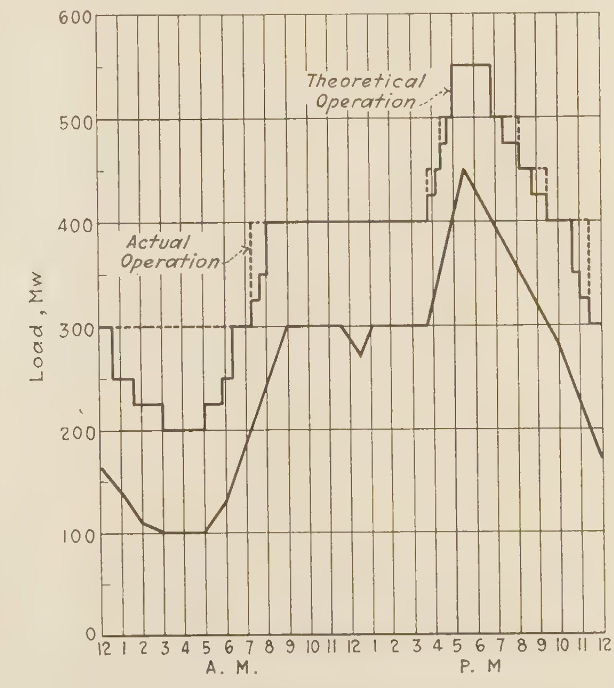


Fig. 6 Load Curves of Actual and Theoretical Operating Sequences

dotted line indicates the sequence which would be followed in practice. Paradoxical as it may seem, the best theoretical operation will result in a loss of $50 per day in the heat consumption alone. This loss is due to the fact that more frequent starts in the theoretical scheme of operation will more than offset a slight increment saving.

In addition to the fuel loss, there will be an increase in maintenance due to more frequent starting and stopping of the units. This loss is very difficult to evaluate quantitatively.

[5] Economy Engineer, The New York Edison Company, Inc., New York, N. Y. Mem. A.S.M.E.

During the periods when there is a rapid change of load which requires putting on a large number of units within a comparatively short time, the operating personnel will be unable to handle the theoretical starting sequence without increase in the operating force. For example, let us assume that we know that four units in station *A* and four units in station *B* must be started within an hour's time, and also that the units in station *A* are all more efficient than those in station *B*, and consequently, all four units in station *A* should be started first. With a limited personnel, it is more practical to start up the units in station *A* and *B* simultaneously, so as to allow an interval of time between starts at each station. Because of the short duration of such periods, the money loss in heat consumption is not great enough to justify adding to the personnel.

In comparing the actual station loads with the loads indicated by the loading schedule, we are interested only in the amount of money lost, due to such a departure, rather than the difference in kilowatts. Very often, the convenience of operation will justify a departure in loading, which, on its face, appears to be large, but upon analysis shows a small money loss.

The criterion of any operating arrangement is the least production cost per kilowatts, all things considered, which is consistent with the system's standards of safety and service. Increment rates and total-input-output curves are nothing but tools and like all tools, if not properly used, may have an adverse effect on the system's economy.

L. J. Parsons.[6] Mr. Mulligan is to be congratulated on his analysis of the problems affecting load division among units. His consideration of the relation between varying load on the frequency-regulating units and those units which operate at fixed throttle is correct if the assumption that a curve of load against time is a straight line for a definite load range is true. In a great many systems the load swings are neither consistent nor uniform. A steam system may be interconnected with a hydro system, which in turn, is connected with other steam and hydro systems which produce swings that are reflected through the entire interconnection, and vary in acceleration and amount over the entire day. The degree of accuracy obtained and the economy involved when working with an average curve, as suggested by the author, is not of great importance, particularly at this time, when the swings are not consistent nor uniform.

In a system with a number of frequency-regulating units, the relative sluggishness of the governors is also an important factor in determining the nature and variation of the swings on the turbogenerators. Until there is an improvement in governor design, and a better coordination of its sensitivity with the automatic frequency regulator, the problem should be approached with caution. There is also a great deal to be done in the matter of regulating frequency between systems which adds to the difficulty.

Fig. 7 of this discussion is an appended curve which shows the variation in load on three major stations of a large steam system. This system is connected with a large hydro system by two ties which have a total capacity equivalent to the capacity of the largest unit in the steam system. The curve marked station *A*, with the most severe fluctuations, is the frequency-regulating station of the system. It has an automatic frequency regulator installed on its largest unit. Although a great deal of improvement has been made since, through the installation of load-bias control on some of the smaller systems connected with the hydro system, nonuniform fluctuating loads are still a big factor. In Fig. 7, the curves for the hydro unit and frequency-regulating station, *A*, *B*, and *C* represent load; the remaining curve represents line-frequency variations.

An automatic frequency regulator which is connected to one turbogenerator is generally set for a definite load range and instantaneous frequency variation, in order that the change in load may conform to the pick-up characteristics of the boilers in the various stations. There is also a certain phase-angle relation between busses of a station and other stations in a large system, which will prevent the distribution of load in accordance with the principles of heat economy. All these limitations do not warrant the use of the incremental curve established from the average input-output curve.

One large system has installed an automatic program-load device which controls the load division of several turbines according to a prearranged economy schedule, but it is doubtful even if this scheme can approach the ideal of a direct relation between time and load. However, such a scheme may not be practicable for another system where the nature of the load, frequency requirements, and load swings are different.

S. Logan Kerr.[7] There will undoubtedly be many diverse

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[7] Research Engineer, I. P. Morris Division, Baldwin-Southwark Corp., Philadelphia, Pa. Mem. A.S.M.E.

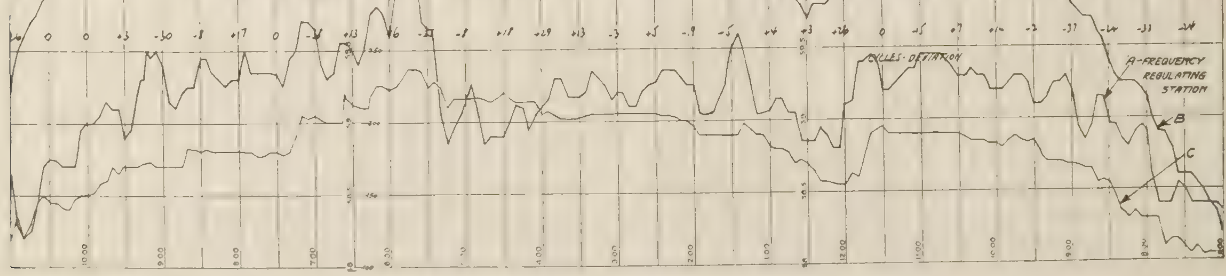


Fig. 7 Load Variation on Three Stations of a Steam System Connected With a Hydroelectric System

opinions expressed in regard to the practical application of the theory advanced in Mr. Mulligan's paper. The limitations in such a theory are, however, not insurmountable and with education of the dispatching personnel, careful engineering of systems, and the coordination of generating plants of different types, it is possible to effect many economies that otherwise would be lost.

The broad principle of economic load division has been known and used for many years, but it has been assumed that the unit characteristics have been similar or that they follow smooth curves or straight lines. The work of F. H. Rogers and L. F. Moody in 1925, referred to by Mr. Mulligan, was the first analysis published on the subject which considered the complex factors and which dealt at length with the question of points of inflection of discontinuities in the characteristic curves. This was a distinct advance in the theory, and showed that these variations in characteristics could not be ignored.

Several outstanding examples of the successful application of these principles can be cited. One of the first operating companies to apply rigid loading schedules to its plant was the Pennsylvania Water & Power Company at the Holtwood hydroelectric plant. The Philadelphia Electric Company has followed these principles carefully in the operation of their steam plants and recently in the operation of the combination of steam and hydroelectric units. The Connecticut Valley Power Exchange under the guidance of Mr. Mayott furnishes a splendid example of the economic coordination of many systems and various types of prime movers.

The enforcement of rigid operating schedules is often impossible of achievement due to the difficulty of maintaining constant supervision of operating personnel, and the clerical work necessary to check operating economy in many plants of small capacity. The use of automatic devices to distribute load according to the schedule for maximum economy has overcome many of the handicaps of manually operated stations, and in several cases has shown amazing improvements in overall operating efficiency. The sponsorship of this work by A. C. Clogher of the Electric Bond and Share Company has resulted in the use of this equipment in the plants of several of their operating companies, and with decided benefits in the reduction of operating losses.

It is interesting to note the experience of one or two plants. At the Norwood hydroelectric development of the Carolina Power and Light Company, the operating efficiency with manual control was in the neighborhood of 90 per cent. With constant supervision this could be increased to 94 or 95 per cent, while with automatic equipment it was rarely less than 97 per cent and usually on the order of 99 per cent.[8] A recent analysis of three major hydroelectric plants in Sweden, undertaken by Elov Englesson of Kristinehamn, showed operating efficiencies of 94.5 per cent, 98.5 per cent, and 91.0 per cent, all of them being operated manually. The operating efficiency in these cases is the ratio of the actual kilowatthours generated to the possible kilowatthours that could have been generated from the same water or fuel at the same load factor.

In making analyses of characteristic curves, the writer has used the same data and essentially the same methods as described by Mr. Mulligan, but has preferred to use input as the abscissas and the first differential output with respect to input as the ordinates. This arrangement results in having the area under the derivative curves represent output, and hence it is quite easy to pick out the arrangement giving the maximum area which, of necessity, gives the maximum output for a given input.

[8] "Automatic Operator a Success," by F. M. Nash, *Electrical World*, August 25, 1930.

### Author's Closure

The author appreciates Professor Berry's correction of his statement concerning the date of the first publication of the basic principles of load division.

Most of the discussion deals with the practical application of the principles of load division and is a valuable supplement to the paper, which aims only to extend the theory.

# Application of the Elastic-Point Theory to Piping Stress Calculations[1]

E. C. Petrie.[2] The authors have presented a solution of the problem of determining stresses and reactions in piping which has simplified to a large extent the work involved in calculating the values. The neutral-point theory is somewhat difficult to follow through, however, for the average engineer designing piping systems who wishes to eliminate as much as possible any operation which involves a knowledge of higher mathematics or mechanics.

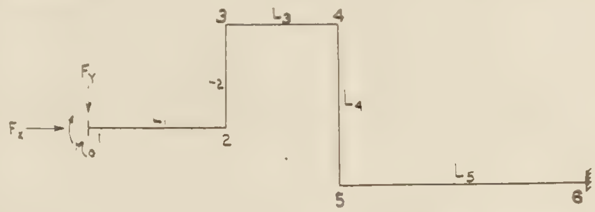


Fig. 1 Diagrammatic Sketch of a One-Plane Piping System

A statically indeterminate system of piping, that is, one lying in a single plane, has three unknown quantities at each of its terminal points. These quantities are the forces and restraining moments caused by the expansion of piping restrained fully at its end points. The authors have given the fundamental formulas for any one-plane piping system, which the writer has rewritten in a slightly different form, as

$$M_0 = (BF_x + CF_y)/A \qquad [1]$$

$$M_0 = (DF_x + GF_y + EI\Delta_y)/C \qquad [2]$$

$$M_0 = (HF_x + DF_y - EI\Delta_x)/B \qquad [3]$$

where $M_0$ is the restraining moment at 1, Fig. 1 of this discussion; $F_x$ is the horizontal force; $F_y$ is the vertical force; $E$ is the modulus of elasticity; $I$ is the moment of inertia; $\Delta_x$ is the deflection along the $X$-axis; $\Delta_y$ is the deflection along the $Y$-axis; and $A$, $B$, $C$, $D$, $G$, and $H$ are the integration constants.

A one-plane piping system similar to those illustrated by the authors is shown in Fig. 1 of this discussion with the values of the integration constants which apply to this particular type of piping layout. The algebraic expressions for these integration constants are

$$A = L_1 + L_2 + L_3 + L_4 + L_5$$

$$B = (L_2^2/2) + L_2L_3 + L_2L_4 - (L_4^2/2) + L_2L_5 - L_4L_5$$

$$C = (L_1^2/2) + L_1L_2 + L_1L_3 + (L_3^2/2) + L_1L_4 + L_3L_4 + L_1L_5 + L_3L_5 + (L_5^2/2)$$

[1] Published as paper FSP-57-10, by S. W. Spielvogel and S. Kameros, in the May, 1935, issue of the A.S.M.E. Transactions.

[2] Engineer, Product Engineering Department, Crane Company, Chicago, Ill.

$$D = BL_1 + L_2 [(L_3^2/2) + L_3L_4 + L_3L_5 + (L_5^2/2)] - L_3 [(L_4^2/2) + L_4L_5] - L_4(L_5^2/2)$$

$$G = L_1 [(L_1^2/3) + L_1L_2 + L_1L_3 + L_3^2 + L_1L_4 + 2L_3L_4 + L_1L_5 + 2L_3L_5 + L_5^2] + L_3 [(L_3^2/3) + L_3L_4 + L_3L_5 + L_5^2] + (L_5^3/3)$$

$$H = L_2 [(L_2^2/3) + L_2L_3 + L_2L_4 - L_4^2 + L_2L_5 - 2L_4L_5] + L_4[(L_4^2/3) + L_4L_5]$$

By means of these constants and formulas [1], [2], and [3] of this discussion, any piping system of the type shown in the writer's Fig. 1 can be analyzed completely by a purely mathematical solution which can be followed through by any engineer who knows the fundamentals of arithmetic.

For simplicity of comparison, the writer will use the same example used by the authors, the conditions of which are given by the authors for the pipe line shown in Fig. 4 of the paper. For this problem, $I = 37$ in.[4]; $E = 25.5 \times 10^6$ lb per sq in.; $\Delta_x = (6.14/100) \times 60 = 3.684$ in.; $\Delta_y = (6.14/100) \times (-12) = -0.737$ in.; and the diameter of the pipe = 6.625 in.

The values of $L_1 = 12$ ft, $L_2 = 18$ ft, $L_3 = 20$ ft, $L_4 = 30$ ft, and $L_5 = 28$ ft, obtained from the authors' Fig. 4 and substituted in the equations for the writer's integration constants give: $A = 108$; $B = 276$; $C = 2976$; $D = -2712$; $G = 105{,}312$; and $H = 14{,}976$.

The substitution of the values of the integration constants into formulas [1], [2], and [3] of this discussion gives

For formula [1]

$$M_0 = (276F_x + 2976F_y)/108 = 2.556F_x + 27.556F_y$$

For formula [2]

$$M_0 = [-2712F_x + 105{,}312F_y - (25.5 \times 10^6 \times 37 \times 0.7378)/1728]/2976$$

$$= -0.911F_x + 35.39F_y - 135.2$$

For formula [3]

$$M_0 = [14{,}976F_x - 2712F_y - (25.5 \times 10^6 \times 37 \times 3.684)/1728]/276$$

$$= 54.26F_x - 9.83F_y - 7288$$

Solving these formulas for $F_x$ and $F_y$, we obtain

$$\begin{aligned} M_0 &= 2.556F_x + 27.556F_y \\ -(M_0 &= -0.911F_x + 35.39F_y - 135.2) \\ \hline 0 &= 3.467F_x - 7.834F_y + 135.2 \\ F_x &= 2.26F_y - 39 \end{aligned}$$

$$\begin{aligned} M_0 &= 2.556F_x + 27.556F_y \\ -(M_0 &= 54.26F_x - 9.83F_y - 7288) \\ \hline 0 &= -51.704F_x + 37.386F_y + 7288 \\ F_x &= 0.723F_y + 140.9 \end{aligned}$$

$$\begin{aligned} F_x &= 2.26F_y - 39 \\ -(F_x &= 0.723F_y + 140.9) \\ \hline 0 &= 1.537F_y - 179.9 \\ F_y &= 117.12 \text{ lb} \end{aligned}$$

$$F_x = 264.65 - 39 = 225.65 \text{ lb}$$

From the values of the reacting forces thus obtained, the restraining and bending moments can be determined. The restraining moment at 0, and the bending moments at points 1 to 6, inclusive, of Fig. 1 of this discussion, which correspond to points $A$ to $F$, inclusive, in Fig. 4 of the paper, are

Restraining moment $M_0$ at 1 = 3804 ft-lb

Bending moment at 2 = $3804 - (F_y \times L_1)$ = 2398 ft-lb

Bending moment at 3 = $3804 - (F_y \times L_1) - (F_x \times L_2)$ = $-1663$ ft-lb

Bending moment at 4 = $3804 - F_y(L_1 + L_3) - (F_x \times L_2)$ = $-4006$ ft-lb

Bending moment at 5 = $3804 - F_y(L_1 + L_3) - F_x(L_2 - L_4)$ = 2764 ft-lb

Bending moment at 6 = $3804 - F_y(L_1 + L_3 + L_5) - F_x (L_2 - L_4)$ = $-516$ ft-lb

In conclusion, the writer believes that the method herein discussed for determining the reacting forces and moments in a one-plane piping system has the following advantages: (1) Integration constants can be determined for any type of piping layout or pipe bend; (2) the method of solving the problem is purely mathematical and requires no graphical layouts; (3) the values can be determined accurately and checked with the same accuracy; and (4) slide-rule calculations will not cause a material difference in the result.

G. A. Hendrickson.[3] The case of a two-ended, one-plane pipe structure with fixed ends, straight elements, and constant cross section has been completely covered by the authors. It might be of interest, however, to note that by redefining some of the terms appearing in Equations [2], [6], and [7], and in several of the unnumbered equations, it is possible to treat three special cases of frequent occurrence, namely, lines with varying cross section, lines with elastic supports, and lines with quarter bends, U-bends, or other radius bends which involve the flattening of curved pipe.

These cases require that the center of the coordinates $O$ of Figs. 2, 3, 4, and 5 of the paper be placed at the centroid of elastic weight, where the elastic weight $W$ is defined by the relation

$$dw = ds/KEI$$

The constant $K$ for straight pipe elements and elastic supports is unity. For an approximate treatment of radius bends, $K$ may be determined in accordance with the methods given in the references of the authors' bibliography.

With this change in coordinates the various moments and products of inertia should be redefined as follows

$$I'_{yy} = \int x^2 dw$$

$$I'_{xy} = \int xy dw$$

$$I'_{xx} = \int y^2 dw$$

Equation [6] of the paper then becomes

$$I'_{11} = I'_{yy} - 2I'_{xy} \tan \alpha + I'_{xx} \tan^2 \alpha$$

Equations [7] then become

$$X_1 = \Delta x_1/(I'_{11} \cos \alpha); \qquad Y = \Delta y/I'_{yy}$$

and Equation [2] retains the same form

$$\tan \alpha = I'_{xy}/I'_{yy}$$

Considering now the case of a pipe structure with elastic supports, it is readily appreciated that the solution for this problem is given when the elastic weight of the supports is included in the determination of the center of coordinates and in the moments and products of inertia of elastic weight. The expansions $\Delta x_1$

[3] Engineer, The Detroit Edison Company, Detroit, Mich. Mem. A.S.M.E.

ıd $\Delta y$ of Equations [7] are determined from the authors' quations [4] and [5] unchanged. These additions, which introıce no complications into the working of the method, make ossible a treatment of the three special cases mentioned preously in this discussion.

For consistency in nomenclature in the authors' Equations 3], [9], and [10], it appears that Equations [1] of the paper ight be rewritten as

$$X_1\delta_{11} + Y_1\delta_{1y} + M\,\delta_{1m} = \Delta x_1$$
$$X_1\delta_{y1} + Y_1\delta_{yy} + M\,\delta_{ym} = \Delta y$$
$$X_1\,\delta_{m1} + Y_1\,\delta_{my} + M\,\delta_{mm} = 0$$

Equation [8] then becomes

$$\delta_{1m} = \int m_1 m\,(ds/KEI) = \cos\alpha \int y_1 dw = 0$$

Equation [9] becomes

$$\delta_{y1} = \int m_y m\,(ds/KEI) = \int x dw = 0$$

ıd Equation [10] becomes

$$_y = \delta_{y1} = \int m_1 m_y\,(ds/KEI) = \cos\alpha \int xy_1\,(ds/KEI) = \cos\alpha \int xy_1 dw$$

These comments regarding derivation of equations are offered ith a view to making that section of the paper easier to follow.

This paper presents a method which can be easily applied to ıe most complex one-plane structures having two ends. So far s the writer is aware no solution of a pipe structure with three r more ends has been published. Further, only a small part f the problems in piping design involves lines limited to one ıane and having two ends without intermediate branch connecons.

Although exact solutions based on simple beam theory are ossible for three-dimensional problems and structures with three r more ends, the most convenient methods resort to approxiations. There is need for an exact solution which embodies l of the simplifications possible in the specialized field of piping. is to be hoped that some one will undertake to solve these roblems for presentation to the Society in the near future.

D. B. Rossheim[4] and A. R. C. Markl.[5] The elastic-point ıeory described by the authors differs in two fundamental reects from the one presented by W. H. Shipman in a paper[6] efore the Society in which three simultaneous equations with x coefficients, set up for the one-plane pipe bend with fixed ıds, were referred to a rectangular system of coordinates with ıe origin at one end of the pipe line. In the paper under discuson, the origin of the system of coordinates is located at the center gravity of the pipe line, and the system itself is no longer ctangular. The relocation of the origin of the system of codinates, suggested in an article[7] by R. H. Tingey, is advantaous in that it reduces the number of coefficients to three, and the uation involving the rotations disappears.

The introduction of the conjugate axis further reduces the umber of coefficients to two, and results in simple expressions r the reactions. This, no doubt, entails a considerable saving work in the calculation of an arch where a number of different loading cases are involved, but this, in the opinion of the writers, offers no advantage in the case of pipe lines where only one type of loading is applied, i.e., thermal expansion.

These considerations have led the writers to retain the rectangular system of coordinates in their standard method of solving pipe-line problems, and to locate the origin at the virtual center of gravity of the pipe line. For any one-plane problem, this results in the following expressions for the reactions:

$$X = EI \times \frac{I_{yy}\Delta x + I_{xy}\Delta y}{I_{xx}I_{yy} - I_{xy}^2}$$

$$Y = EI \times \frac{I_{xy}\Delta x + I_{xx}\Delta y}{I_{xx}I_{yy} - I_{xy}^2}$$

Applying these formulas to the example given in the paper and utilizing the authors' values of $I_{xx}$, $I_{yy}$, and $I_{xy}$, we obtain

$$X = \frac{25.5\times 10^6 \times 37}{144} \times \frac{6.14}{12\times 100} \times \frac{23{,}306.667\times 60 + 10{,}317.333\times 12}{14{,}270.667\times 23{,}306.667 - 10{,}317.333^2} = 225.56$$

$$Y = \frac{25.5\times 10^6 \times 37}{144} \times \frac{6.14}{12\times 100} \times \frac{10{,}317.333\times 60 + 14{,}270.667\times 12}{14{,}270.667\times 23{,}306.667 - 10{,}317.333^2} = 117.10$$

It is seen that steps 3, 4, 5, and 6 of the authors' method are eliminated. The bending moments are obtained in the same way as shown in the paper.

The principal labor involved in applying these formulas consists in the evaluation of $I_{xx}$, $I_{yy}$, and $I_{xy}$, especially where radii introduce the additional influence of the flexibility factor. To facilitate and expedite the solution of problems, these values can be worked out in general terms for a number of layouts to cover every probable case, thus reducing the solutions to a routine suitable for the drafting room.

A. E. R. de Jonge.[8] The method of calculating the end reactions of statically indeterminate pipe lines, subjected to heat expansion, by means of the "elastic center" is, in essence, the analytical equivalent of the method which uses the ellipse of elasticity for this purpose. As far as is known to the writer, the method of the "elastic center" was discovered around 1870 by Prof. K. Culmann,[9] Zurich, by the use of the ellipse of elasticity. Only much later did analytically minded engineers transform Culmann's graphical solution into an analytical solution and it appears that this was first done by Professor Müller-Breslau, Berlin, who gave the derivation which is now commonly used by structural engineers.

The authors have followed rather closely this latter method and have derived the basic formulas by the work equation (principle of virtual work). Unfortunately, the authors have omitted to give a list of notations, so that it is left to the reader to find out for himself, by reference to the formulas, what the various symbols mean.

This leads to confusion, for instance, where $\zeta_{my}$ is cited to be an angular displacement which, according to Maxwell's law, must be equal to $\delta_{ym}$, i.e., to a linear displacement. Yet, this discrepancy is only apparent, and could have been avoided by a more careful explanation. On the whole, however, the derivations seem to be correct.

[4] Mechanical Engineer, The M. W. Kellogg Company, New York, . Y.

[5] Ibid.

[6] "Design of Steam Piping to Care for Expansion," by W. H. Shipan, Trans. A.S.M.E., vol. 51, part 1, 1929, paper FSP-51-52, pp. 5–446.

[7] "Method of Calculating Thermal Expansion Stresses in Piping," R. H. Tingey, *Marine Engineering and Shipping Age*, vol. 39, no. 4, pril, 1934.

[8] Babcock & Wilcox Company, New York, N. Y. Mem. A.S.M.E.

[9] "Die Graphische Statik," by K. Culmann, second edition, 1875, pp. 399 et seq.

Whether or not the authors can claim the discovery of the transfer formula is a matter of opinion because the "transformation" formula is the usual one employed for deriving the moments of inertia of systems for inclined axes, when those for other axes are given. Professor Culmann[10] who was the originator of the theory of the "elastic center" was also the first to use this transformation formula. However, he used it in a general form applicable to any system of coordinates, while the authors have taken this formula and applied it to the special case of rectangular coordinates.

The authors claim simplicity, time saving, and elimination of sources of error for the method they have presented, but, in respect to the last item, their admission is of interest that slide-rule accuracy is insufficient and that one set of solutions frequently fails to satisfy the equations because an insufficient number of significant figures has been used. This fact has recently been verified by the writer in the case of a pipe line having great length compared with the lateral dimensions. Five-place logarithm tables did not give accurate values and six decimal places behind the decimal point of all linear dimensions had to be used at all times in order to arrive at a correct result. This fact makes the calculations for the evaluation of the integrals by the method presented by the authors very cumbersome and tedious, even when a calculating machine is used.

The statement is made in the paper that the moments at points between the two supports are "materially affected by slight changes in the values of the end reaction." The writer finds himself unable to agree with this statement as it is rather the moments of inertia and the products moment of the pipe line as a whole which considerably influence both the force of reaction and the moments between the supports by influencing the angle $\alpha$ of the inclined axis. For this reason, the greatest accuracy has to be exercised in the calculation of these moments of inertia and particularly of the products moment. The latter, especially, is a source of trouble in so far as the positive and negative components often have values of nearly the same order of magnitude. However, since it is their difference that counts, a large number of significant figures has to be used in order to obtain even a moderate degree of accuracy. This is a serious drawback to the use of this method.

There exists still another difficulty which complicates matters. For pipe lines which have great length compared with the lateral dimensions, the angle $\alpha$ of the inclined axis becomes very small, as a rule less than 5 deg. In that case the ordinary interpolation gives quite wrong results and more complex interpolation formulas have to be used in order to obtain fair accuracy, particularly when the angle falls below 3 deg. These are serious drawbacks which are inherent in the method described by the authors.

It is not quite clear to the writer why the authors use the terms "elastic point" and "neutral point," when "elastic center" is the standard accepted term. This point is the center of the "elastic weights" of the system and its proper designation is, therefore, "elastic center," a term which the authors, by the way, have also used. In order to avoid further confusion it appears advisable to adhere to the term "elastic center" and abandon the others used by the authors.

Attention to the use of the theory of the "elastic center" for the calculation of pipe lines has already been drawn, in 1930, by A. A. Bato as well as by the writer in their discussion of a paper by Messrs. S. Crocker and A. McCutchan[11] in which the authors used for the calculation of the reactions in pipe lines, due to heat expansion, a method which they called the "graphoanalytical" method. Both Mr. Bato as well as the writer stated at the time that the question of plane pipe lines can be dealt with much easier by using the "elastic center" of the pipe line as a whole, a method well known to structural engineers and used by them for decades for the calculation of arched girders. The writer had stated further that the solution of this problem is most readily accomplished by using the theory of the ellipse of elasticity[12] to which he had already drawn attention in 1928.

[10] "Die Graphische Statik," by K. Culmann, second edition, 1875, p. 400.

[11] "Frictional Resistance and Flexibility of Seamless-Tube Fittings Used in Pipe Welding," by S. Crocker and A. McCutchan, Trans. A.S.M.E., vol. 53, 1931, paper FSP-53-17. See discussion pp. 234–237.

[12] "Graphical Methods for Least Squares," by E. O. Waters, Trans. A.S.M.E., vol. 51, part 1, 1929, paper APM-51-18. See discussion pp. 209–210.

### Author's Closure

The authors, in presenting a new method of calculating piping problems, laid no claims to originating a new theory and indeed referred to an exhaustive essay on this theory in the bibliography of their paper. In view of the fact that general statements of possible methods of procedure, such as appear in the discussions to several other A.S.M.E. papers on this subject, are of little help to the engineer, who may have neither the time nor the inclination to engage in theoretical research, the authors went to the root of the problem and presented another method; thus enabling the engineer to check his calculations by means of dissimilar processes.

The paper points out, and some of the discussion is in agreement, that in certain instances a very slight deviation in calculated end reactions is sufficient to cause serious discrepancies in the calculation of bending moments. Under these circumstances it is not worth while to presume that results within the desired degree of accuracy can be obtained by graphical methods, particularly by one requiring the construction of an ellipse. Results so obtained can at best be only approximate, and should only be used for preliminary design, the final design being based upon the results of analytical calculations.

Mr. Hendrickson's suggestion, that by redefining some of the terms the method may be broadened to include special piping problems, is an excellent one. The authors have not studied this phase of the subject closely, but it is evident that where the deflections of a pipe line due to its being suspended with spring hangers is known, the method can be applied by using the centroid of elastic weight rather than the static centroid.

Mr. Petrie's contribution to the discussion is another way of solving the equations given by W. H. Shipman.[6] It is apparent that the coefficients $A$, $B$, $C$, $D$, $G$, and $H$ must be computed for each pipe line. This can be done by applying the integrated formulas given by Mr. Shipman in his paper. In addition there remains the problem of solving three simultaneous equations.

The authors are acquainted with the equations given by Messrs. Rossheim and Markl. These equations involve the products and differences of very large quantities. Their derivation is not as easily demonstrable as is the case with the equations developed from the theory of the elastic center.

# Water Gaging for Low-Head Units of High Capacity[1]

Lewis F. Moody.[2] The writer feels that Mr. Mousson and the other members of the Engineering Staff of the Safe Harbor Water Power Corporation, as well as the executives of that company, deserve the appreciation of all engineers working in the hydraulic field for the tremendous expenditure of time, effort, and financial outlay involved in the long series of researches on current-meter measurement which they have carried out, and that Mr. Mousson deserves our thanks for the thorough and careful presentation of the methods and results which he has given in this paper.

The excellence of the test equipment used at Safe Harbor and the meticulous regard for detail are evident from the paper, and much credit is due the testing organization for their efforts to insure exactness of measurement. In the writer's opinion, however, two major questions stand out, which no amount of refinement in equipment and procedure can circumvent. The writer wonders (1) whether the metering section itself was adequate for a precise measurement, and (2) whether, with the high degree of turbulence superposed on the obliquity of flow existing over a considerable part of the section, the two-meter angular-correction method would necessarily assure dependable results. The behavior of the meters themselves showed a high degree of obliquity of flow and turbulence, both when the false roof was used, and when it was omitted. The turbulence is readily accounted for by the presence of the rack structure immediately upstream from the section of measurement, including 24-in. I-beams and closely spaced intermediate beams. The corrections required by the two-meter method were large; and the writer believed when the tests were called to his attention that insufficient evidence existed to demonstrate the correctness of the assumptions on which the method is based, when applied in the new manner and under the extreme conditions here involved. The writer also believed that the Safe Harbor organization would welcome any light which could be thrown on these questions, and they have shown an open-minded attitude and have heartily cooperated in efforts to investigate the problem by certain special experiments, suggested by the writer, and carried out at the Princeton Engineering School. As a supplement to Mr. Mousson's paper the writer will describe briefly these experiments,[3] which were made possible by the Safe Harbor Company in loaning for use in these experiments four of the meters used in their tests. The work was carried out under the direction of the writer and Prof. A. E. Sorenson, by two graduate students, L. F. Moody, Jr., and R. S. Hackett. The Safe Harbor Company have recently taken two further steps which should be most effective as demonstrations of the dependability or limitations of the method when applied as described in Mr. Mousson's paper. These steps include a test with the racks and supporting structures removed, using the type-1 and type-3 meters; and a Gibson test. The comparison of the results by these two new tests with those obtained under the conditions described in the paper should be most illuminating.

Before describing the Princeton experiments,[3] the writer would explain his reasons for doubt as to the dependability and possible limitations of the two-meter angular method. The oblique calibration of meters, and the two-meter angular method, were proposed by the writer about twenty years ago, and a considerable amount of laboratory research was carried out at Rensselaer Polytechnic Institute at Troy, N. Y.[4] The method was actually applied by B. F. Groat and the writer to the flow measurement of the Illinois River at Massena, Ill., in 1914.

The object as explained by Mr. Mousson, is to correct the results based on the still-water calibration of the meters for the effect of obliquity of flow encountered in running water. That the method is logical when applied to flow of permanent obliquity seems reasonable; but whether it is dependable for highly eddying or turbulent flow involves other considerations. The complexity of the flow conditions encountered by individual vanes of a meter, when passing through a body of water filled with moving eddies, defies analysis. At times, as pointed out by Mr. Mousson, even when the average obliquity of flow is not great, a meter will stall, as shown by its record; but even before this extreme condition is met, the meter may fluctuate greatly in speed and may momentarily stall without making the action evident in its record; and individual blades may stall or greatly vary in their action without stalling the meter. When the two-meter method was proposed, it was the thought that if two meters are used in flowing water, one of which slightly overregisters, and the other slightly underregisters, as shown by their oblique still-water ratings, and if the flow is sufficiently smooth to give measurements by both meters which differ by only a small amount, the true answer must lie somewhere between the two results, and that a weighted mean derived from the angular calibrations would best represent the probable flow.

When, however, as at Safe Harbor, both meters underregister in steady oblique flow, and when, as in the case of the conical-screw type-2 meter, the underregistry is great, and when further, the flow is highly turbulent, the extension of the method to the point of extrapolating the result above the indications of both meters appears to introduce new questions and doubts.

The most dependable answer would be the comparison of the results with a direct volumetric measurement, or with a measurement by a method of demonstrated accuracy. Unfortunately, no entirely satisfactory evidence of this kind is known to the writer. The Walchensee (Obernach) tests, referred to by Mr. Mousson, were not at all satisfactory, and Mr. Mousson in his discussion[5] of Hunter Rouse's paper pointed out their limitations. They did not involve, for example, the use of a battery of meters, but only one of each type, and the spread of the results was so great that the variations exceeded the small differences in question. The Holtwood tests were made under such smooth flow conditions that the two-meter method may well be applicable to such flow, and throw no light on the phenomena of highly turbulent flow.

It was the writer's opinion that if the water in a rating flume were disturbed by lateral jets of water introducing no longitudinal components in the direction of motion of the rating car, the effect of at least one kind of turbulence should be clearly evident. While the meter registration could still be compared with the actual speed of the car, the meter would be passing through disturbed water instead of still water. If the two-meter angular-calibration method is to be above suspicion, it should give, from the readings of the two meters, the correct speed of the car by calculation from the angular-correction curves. The experiments[3] conducted by L. F. Moody, Jr., applied this principle.

Three water jets were introduced from the side of the rating

[1] Published as paper HYD-57-10, by J. M. Mousson, in the August, 1935, issue of the A.S.M.E. Transactions.

[2] Professor of Hydraulic Engineering, Princeton University, Princeton, N. J. Also Consulting Engineer, Baldwin-Southwark Corporation, Philadelphia, Pa. Mem. A.S.M.E.

[3] Described by L. F. Moody, Jr., and R. S. Hackett in their theses submitted as partial requirement for an advanced degree, Princeton University, Princeton, N. J. (Unpublished.)

[4] "Measurement of the Velocity of Flowing Water," by L. F. Moody, Proceedings of the Engineers Society of Western Pennsylvania, vol. 30, no. 4, May, 1914. Also discussion of this paper in vol. 30, no. 5, June, 1914.

[5] J. M. Mousson's discussion of "Research Institute for Hydraulic Engineering and Water Power," by Hunter Rouse, Trans. A.S.M.E., vol. 55, no. 10, 1933, paper HYD-55-3.

tank and diffused somewhat by spiral baffles in the nozzles, the arrangement being shown in Fig. 1 of this discussion. Fig. 2 of this discussion shows the distribution of the lateral flow. All details of procedure and diagrams showing the results are available

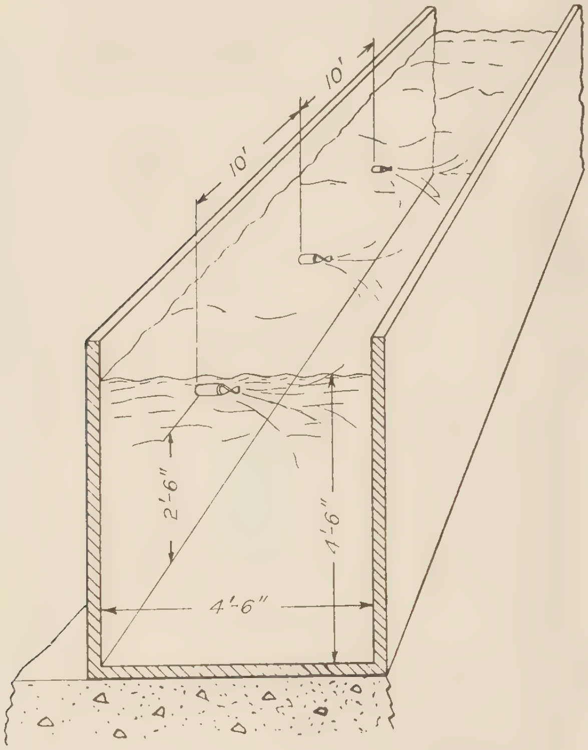


Fig. 1 Arrangement of Jets in the Flume

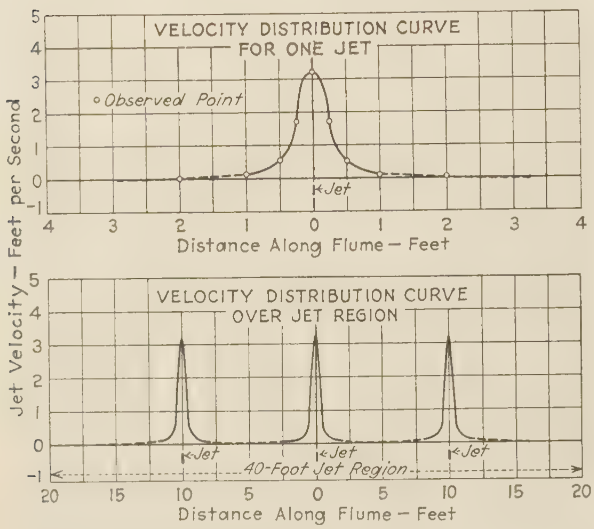


Fig. 2 Velocity Distribution of Lateral Flow From Jets Shown in Fig. 1

in the thesis.[3] A tabulation of the results for three velocities of the car are given in Table 1 of this discussion. It will be seen from this table that the application of the angular two-meter method of calculation to the registrations of the meters did not give the actual speed of the car, but a value higher than the true speed. The author of the thesis concludes: "It is evident, however, from calibration sheet III that the tendency is, by the angular method, to give increasingly greater error with increase in turbulence."

TABLE 1 RESULTS OF PRINCETON TESTS

| | Left-hand meter | Right-hand meter | Left-hand meter | Right-hand meter | Left-hand meter | Right-hand meter |
|---|---|---|---|---|---|---|
| True velocity of car $V$, fps | 2.5 | | 3.5 | | 4.5 | |
| Velocity recorded by type-1 meters based on still-water rating, $V_1$, with jets in action. Length of run = 40 ft | 2.500 | 2.498 | 3.502 | 3.498 | 4.497 | 4.497 |
| Average $V_1$ | 2.499 | | 3.500 | | 4.497 | |
| Velocity recorded by type-2 meters, based on still-water rating, $V_2$, with jets in action. Length of run = 40 ft | 2.373 | 2.373 | 3.383 | 3.376 | 4.393 | 4.393 |
| Average $V_2$ | 2.373 | | 3.380 | | 4.393 | |
| Differences of recorded velocities by type-1 and type-2 meters in per cent of velocity of type-1 meter = $[(V_1 - V_2)/V_1]100$ | 5.043 | | 3.430 | | 2.313 | |
| Correction, by angular method from angular-correction chart, in per cent of $V_1$ | 1.550 | | 1.000 | | 0.660 | |
| Derived or computed velocity by angular method = $\frac{100 + \text{angular correction}}{100} \times V_1$ | 2.538 | | 3.535 | | 4.525 | |
| Error by angular method, in per cent of true velocity of car = $\frac{\text{Derived vel.} - \text{true vel.}}{\text{True vel.}} \times 100$ | 1.520 | | 1.000 | | 0.556 | |

Mr. Mousson in a very constructive discussion of this thesis has analyzed the results by applying the oblique calibration curves to the instantaneous velocities encountered throughout the run, and by integration has thus accounted theoretically for the nature of the results. However, when the two-meter method is applied in the field, it is impossible to analyze and to integrate the instantaneous actions, and the method is applied to the overall result, just as was done in these experiments.

Mr. Mousson also pointed out that the type-2 meters were subject to stalling at the instant of encountering the maximum lateral velocity. This condition may also exist in the field, and undoubtedly does in the Safe Harbor tests with this meter. Moreover, partial stalling or stalling of single blades, may occur even when the turbulence is much reduced. The plotting of the results showed that while the error decreases with decrease in relative turbulence, it does not disappear within the range of the tests.

The second investigation, carried out by Mr. Hackett, was directed toward the effect of pulsations in magnitude of the velocity, rather than its direction. The tests were for the same purpose as those described by Mr. Mousson, made at the Bureau of Standards by varying the car speed. In the Princeton tests, however, the test could be made much more accurately. The meters were mounted on a swinging frame, which was oscillated through a small angle by a crank and link, driven from an axle of the car. The oscillation was such as to vary the meter speed without reversing it. As might be expected from the helicoidal generating lines of the meter blades, and as previously found by Yarnell and Nagler,[6] with meters oscillated about a fixed point, in running

[6] "Effect of Turbulence on the Registration of Current Meters," by D. L. Yarnell and F. A. Nagler, Transactions of the American Society of Civil Engineers, vol. 95, 1931, p. 766.

water, the pulsations were found to have no effect on the meter registration.

A few further points regarding the Safe Harbor tests might be mentioned. It is believed that the choice of the conical-screw type-2 meters, was unfortunate, due to the form of the propeller which has curved generating lines and which gives for lateral components of flow an effect approaching that in a cup meter, tending to pick up turbulence in a manner similar to a Price meter, but in a direction to retard the meter. This point seems to be borne out by the Princeton experiments.[3]

The writer also believes that the combination of the type-1 and type-3 meters is unsatisfactory for the reason that since there is so little difference between their angular characteristics, the correction called for by the two-meter method is more than 50 per cent greater than the difference between their indicated results. That is, it would be necessary to extrapolate to get the supposed true value to an extent much greater than the difference detected in the tests. When the method is applied to tests made successively and not simultaneously, the difficulty in preserving exactly constant flow conditions, and the inevitable variations in results experienced in repeat tests of a turbine, may completely distort the relatively small differences due to the change in meter type and give a totally unreliable final result. For example, if the two types of meter give indications differing by 0.7 per cent, and if the measurements are both subject to an error of only 0.25 per cent, then the final calculated flow may be anything within a range of over two per cent, or the result would be subject to an error of over ± 1 per cent.

As to possible lines of further development, directed toward overcoming the difficulties inherent in the problem of precise measurement by current meter, the writer believes it would be worth while to direct further attention to the meter itself. It should be possible to develop axial-flow meters having very slight underregistering characteristics, and also meters slightly over-registering in oblique flow. Some progress was made at Rensselaer Polytechnic Institute at Troy, N. Y., in this direction prior to 1915. One method was the use of a stationary circular shield around the propeller. A paper by F. Anlauft[7] shows such meters developing promising characteristics.

In conclusion, the writer expresses the hope that Mr. Mousson and his associates will be able to continue their valuable researches in this field, and that further clarification of the problem will result from their work.

F. H. Rogers.[8] The paper is a valuable contribution to the subject of current-meter testing in large intakes of hydraulic turbines. The excellence of the equipment, and the great care taken in testing were justified by the consistency of the results obtained. The author points out clearly the importance of carefully considering the types of meters to be selected and the great accuracy required in the meter calibrations.

The accuracy of the field tests made by the two-type current-meter method is based on the assumption that angular still-water calibrations can be used to correct the meter registration in flowing turbulent water without conclusive proof of such assumption.

The author describes a calibration test of this method made previous to the field tests in which the meters were installed in flowing water in the flume at the Holtwood Laboratory, and the readings compared with the actual discharge obtained from a calibrated venturi meter and states that this test gave satisfactory results. From a study of the results of this test, shown in Table 1 of the paper, it appears that the flow conditions in the Holtwood flume differed considerably from those existing in the metering sections of the large turbines. For example, in the flume at Holtwood the difference between the registration of the meters was only 0.51 per cent for smooth flow and 1.69 per cent for rough flow, requiring, even for rough flow, a correction to type-1 meter of only 0.49 per cent, and indicating but very little obliquity.

In the field tests, however, the following readings were obtained:

1 Unit with false roof: (*a*) The difference in registration of the meters was 3.9 per cent, (*b*) the correction to the type-1 meter was 1.06 per cent, and (*c*) the corresponding angularity was 10.5 deg.

2 First test on the unit without false roof: The type-2 meter stalled at certain locations, indicating an angularity of flow in excess of 34 deg at these points.

3 Final test on the unit without false roof using type-1 and type-3 meters: (*a*) The difference in registration of the meters was 0.7 per cent, (*b*) the correction to type-1 meter was 2.1 per cent, and (*c*) the corresponding angularity was 14 deg.

The flow conditions at the metering sections of the turbines, therefore, are not truly comparable with the conditions in the Holtwood flume.

In describing the tests on the unit with the false roof the author emphasizes that the effective obliquity of 10.5 deg, obtained from the angular still-water ratings, is to a considerable extent an effective angularity of individual water particles and flow filaments rather than a general obliquity of flow. This rather erratic behavior of separate water particles is certainly true, as proved by many experimenters, and has been mentioned in two other papers.[9,10]

A comparison between the physical conditions at the meter during the angular still-water rating and the field tests is here suggested for consideration.

1 Angular still-water rating:

(*a*) At a given point on the meter, during the registration period, the obliquity and velocity are constant.

(*b*) At any given time during the registration the obliquity and velocity are constant across the entire face of the meter.

2 Field tests:

(*a*) At a given point on the meter during the registration period both the obliquity and velocity vary.

(*b*) At any given time during the registration there is a variation in obliquity and velocity across the face of the meter.

Considering these wide differences in flow conditions, there appears to be little foundation for assuming that the correction curves obtained from the angular still-water rating can be applied to the field results, particularly where turbulence is present. The possible error is shown by the conclusion reached by Mr. Mousson that the discharge recorded by type-1 meter must be increased, and Mr. Kerr's[10] findings that the discharge recorded by this meter should be decreased.

It is to be hoped that the valuable research work accomplished by the Safe Harbor Power Corporation and others can be continued in order to eliminate the remaining uncertainties in this method of water measurement.

J. F. Roberts.[11] A most important contribution to the art

[7] "Hydrometrische Flügel bei schräger Anstromüng," by F. Anlauft, Mitteilungen des Hydraulischen Institute der Technischen Hochschule München, vol. 5, 1932, pp. 1–20.

[8] Chief Engineer, I. P. Morris Division, Baldwin-Southwark Corporation, Philadelphia, Pa. Mem. A.S.M.E.

[9] "Photoflow Method of Water Measurement," by W. M. White and W. J. Rheingans, Trans. A.S.M.E., vol. 57, August, 1935, paper HYD-57-7, p. 273.

[10] "Research Investigation of Current-Meter Behavior in Flowing Water," by S. Logan Kerr, Trans. A.S.M.E., vol. 57, August, 1935, paper HYD-57-9, p. 295.

[11] Hydraulic Engineer, Power Corporation of Canada, Ltd., Montreal, P. Q., Canada.

of water measurements by means of current meters has been described in Mr. Mousson's paper. It is a fact that by slowly moving the meters over the area to be metered, the mean velocity of that area is obtained just as accurately as though the meters had been stopped at designated points and a large number of point velocities computed. The writer ventures to say that any tests in the future, where current meters are used, will follow this procedure.

In the writer's opinion, Mr. Mousson is very conservative when he states the saving in computation time effected by the traversing system or vertical integration method. One day per test for computations instead of four days is certainly a worthwhile saving but the writer believes this could be even further decreased and still obtain reasonable accuracy with the integrating system. With this system it should be feasible to eliminate the recording charts and use a cyclometer which reads directly the net forward revolutions of the meter. It might even be feasible to so mount one meter that it could be traversed both vertically and horizontally, thus further decreasing the cost of instruments and simplifying the computations, although slightly increasing the testing time.

The writer has one question: Under part (c) of "Testing Procedures and Computations," page 312, the author mentions the necessity of correcting the runs for type-1 and type-2 meters for the same turbine output, according to the readings of the piezometers recording on the index system. How much actual correction was necessary between comparative tests with type-1 and type-2 meters when the load was presumably constant? In other words, was there any appreciable change in flow during a test?

About three years ago the writer was interested in current-meter tests conducted on the 12,000-hp, adjustable-blade propeller turbines operating under a head of 26 ft at the Back River plant. Five current meters of the Texas-Ott V-type, with three square vanes mounted on radial spokes, were used. These were similar to the type-1 meter used by the author, and were also provided with plaster template molds and a 10-pen graphic recorder, the action of which was very similar to the author's. The pitch of the meters was about 25 cm, or the same as those used by Mr. Mousson. These meters were mounted on a horizontal bar fixed into guides which fitted into the head-gate slots, the whole being raised and lowered by the gate-house crane.

The Back River turbines have three openings, each 15 ft wide by 25 ft deep. Readings were taken at seven different elevations, giving 35 readings per opening, or 105 readings per test. Computations were simplified as much as possible, because relative performance between different runner tilts, gate openings, and between units built by two different manufacturers was the answer wanted. Since all of the meters had practically the same rating coefficient, the meters were so distributed that the same coefficient could be used for all meters. With each reading representing approximately equal areas, all the readings were converted to velocity after which the 105 readings per test were averaged.

Results were very satisfactory. Points could be duplicated within 0.5 per cent and results, when plotted, formed remarkably smooth curves. A maximum overall efficiency from water to switchboard of about 88 per cent was obtained. While it was felt that this was possibly 2 per cent to 3 per cent on the high side, it was considered very satisfactory for our purpose. From the test results splendid operating curves could be constructed showing how to generate the greatest number of kilowatt-hours under all conditions.

Based on Mr. Mousson's paper, the writer would conclude that the type of flow meter used by the writer would underregister between 1 per cent and 2 per cent, so that his results should be decreased by that amount.

Personally, the writer believes that satisfactory test results can be obtained by the use of current meters and there is no doubt but that Mr. Mousson has contributed a large amount of useful information whereby future tests cannot only be made cheaper, but also better.

W. M. White[12] and W. J. Rheingans.[13] This paper gives an excellent account of the difficulties encountered in the measurement of large quantities of water with current meters, especially if turbulent flow is present. The Power Company that made the tests is to be congratulated upon the perseverance shown and the time and money spent in trying to arrive at the facts. Certainly all details of testing, application, and computation were carefully made and all possible sources of error were investigated.

However, Mr. Mousson apparently is not very familiar with the work done with current meters in testing hydraulic power plants in the United States and Canada. Up until 1923, before the Allen salt-velocity and the Gibson methods were first introduced, the current meter and pitot tube were about the only available means for measuring large flows, with the exception of an occasional weir test or a laborious salt-titration test. Since the pitot-tube tests were confined largely to a few high-head plants, the current meters were quite extensively used for testing hydraulic power plants.

The difficulties encountered and the unsatisfactory results obtained in turbulent flow prompted the development of other methods of water measurement. At the same time, every attempt was made to obtain accurate tests with current meters. Many of the improvements mentioned by Mr. Mousson as having been recently developed in Europe were used in the United States and described in publications ten to twenty years ago. For instance, the movable supporting frame for multiple meters was used at the Massena tests in 1914, and was described in detail by Benjamin Groat in a paper[14] presented before the A.S.C.E. In this particular test the velocities were measured at 100 points in a cross-sectional area of 625 sq ft, which compares favorably with the number of metering points being recommended for present-day practice.

Use was also made of the two-type current-meter method of measurement of turbulent flow. A Haskell and an Ott meter were used, both of which underregistered the cosine component of angular flow. The discharge corrections were applied by plotting composite curves very much similar to those described and shown in the paper by Mr. Mousson.

The two-type current-meter method as used at Massena in 1914 and as described by Mr. Mousson for the Safe Harbor tests, is based entirely on the theoretical assumption that turbulent flow can be resolved into the two simple elements of angular flow and variations in the velocity of the forward flow. From this assumption it is concluded that the current meter will perform exactly the same in turbulent flow as when rated in still water at various angles to the direction of motion of the rating car.

If this is true then a current meter which will underregister the cosine component of angular flow when rated in still water, will always underregister in turbulent flow and will never overregister. Similarly, a current meter which overregisters the cosine component of angular flow will always overregister in turbulent flow and will never underregister.

That this is not the case was proved by tests made by Yarnell

[12] Manager and Chief Engineer, Hydraulic Department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis. Mem. A.S.M.E.

[13] Test Engineer, Hydraulic Department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

[14] "Chemihydrometry," by B. F. Groat, Trans. A.S.C.E., vol. 80, 1916, paper 1366, p.

and Nagler.[6] In these tests current-meter traverses were made in a 3-ft × 4-ft flume with various types of turbulent flow. It was found that the Ott meter, which underregisters the cosine component of angular flow in still water, would overregister by as much as 50 per cent in certain types of turbulent flow and underregister as much as 20 to 30 per cent for a different type of turbulent flow. The same was true of the Hoff meter. On the other hand, the Price meter underregistered 17 per cent for one type of flow and overregistered 54 per cent for another type. It is true that Yarnell and Nagler[6] used only a single rotation for each meter, but they made tests with a four-blade Hoff meter which had a right-hand rotation and an Ott meter having a left-hand rotation. Both meters showed the same characteristic of underregistering or overregistering a certain type of turbulent flow, showing that the direction of rotation had very little effect on the results.

Just such variations as were obtained with the Ott, Hoff, and Price meters in turbulent flow by Yarnell and Nagler,[6] may be expected in field tests where it is impossible to determine what type of turbulent flow is present. As long as there is a possibility that the meters may show variations from a minus 30 per cent to a plus 50 per cent for various types of turbulent flow, any attempt to measure the turbulence and correct for it by using differences of indicated flow as small as 2 or 3 per cent between two types of meters, is bound to be a failure.

Up to the present time the preponderence of evidence is against the two-type current-meter method. As stated before, it is based entirely upon a theoretical consideration of being able to resolve turbulent flow into simple elements. The only practical proof so far has been a test made at Holtwood, mentioned by Mr. Mousson. However, the amount of disturbance introduced by the racks in this test was apparently very small as compared to what can usually be expected in field tests.

Therefore, before the two-type current-meter method of testing can be accepted for measuring turbulent flow, extensive tests will have to be made similar to the ones stated by Yarnell and Nagler,[6] in which current-meter traverses are made in all types of turbulent conditions with a known quantity of flow. These tests would have to show conclusively that the two-type method with the meters adopted gives accurate results for all types of turbulent flow and under all possible conditions which may be encountered in the field.

P. F. Danel.[15] Progress in hydraulics has always depended upon accuracy in water measurement. No theory can be constructive unless it can be checked, and in most cases it may be assumed that theories used in design are no more accurate than the measurements themselves.

For a number of years many laboratories have been conducting model tests having an accuracy of 0.5 per cent but in most cases field tests have not attained by any means this same degree of accuracy. The author's contribution takes us one step farther toward accurate field tests.

This is of prime importance, not only in ascertaining the performance of the units, but also in giving the designer new data to assist in improving design theories and in enabling closer prediction regarding the performance of future units. Unfortunately, with most of the accumulated data the trends which the designer is eager to discover are overshadowed by the errors in the test. This is particularly true in large low-head developments, which, as new comers into the field of power development, require special adaptation of older test methods and the development of new.

Most laboratories resort to rating with a moving car running above a still-water flume. Errors in the length of travel or in the corresponding time are easy enough to avoid, but, nevertheless, have not been uncommon and still are a probable cause of many inaccuracies. The influence of disturbances in the rating flume can, as pointed out by the author, account for further discrepancies, while unsteady motion of the car, resulting from misalignment of the rails may introduce still further errors. In this case the consistency of the test points is impaired and the accuracy becomes less.

The new way of plotting the test points shown in Fig. 15 illustrates certain features of a meter's behavior at low velocities. These are of interest not only in rating the meter, but also in designing new meters. Literature on meter testing is abundant, but that on meter design is scarce and much needed.

Systematic tests with different grades of oils with various viscosities are of great practical importance since the effect of viscosity has too often been overlooked. The writer knows of cases where tests have been in error by more than 3 per cent through the use of improper oil.

Inasmuch as there appears to be no possible way of rating accurately in flowing water, some method of using still-water ratings in turbulent flow must be resorted to, and therefore this paper is a valuable contribution on this subject.

It may be mentioned that in Europe the one-meter method is usually employed, and if the location of the test section is appropriate comparatively little error arises. The two-meter method may be recommended in cases where there is steady oblique flow as is frequently the case in converging flumes or penstocks, as well as in bellmouths with good approach conditions. For such tests, type-1 and type-3 meters of the paper, would apparently be suitable provided that the type of meter which is used has appropriate characteristics, as pointed out by the author.

In pulsating flow, with more or less periodic obliquity of flow, the accuracy of the two-type-meter method is probably greatly impaired and the advantage over the one-meter method is not so distinct as with steady oblique flow.

The practical range of application of the two-type-meter method is then not as great as it might appear at first thought. In deciding, therefore, between the use of the one-type meter and the two-type-meter method, a careful study of hydraulic conditions must be made. Other things being equal, the former method will often be resorted to for simplicity, low cost, and because it is better understood. Nevertheless, with steady converging flow, the latter method is probably the most accurate way of using current meters.

Improvement in the design of current meters will undoubtedly tend to widen the range of accurate application of the one-meter method, and the author's work in developing his type-3 meter is a step forward in this direction.

### Author's Closure

Because of the turbulence caused by the trash racks, Professor Moody doubts whether the gaging sections available at Safe Harbor were adequate. He believes, however, that a current-meter test without the trash racks and a Gibson test would be most effective in demonstrating the dependability or the limitations of the two-meter method.

In the original paper, page 314, in the next to the last paragraph, the following statement was made in regard to the tests without the racks: "The results indicated that the effective obliquity was slightly less when compared with the one previously obtained. The discharges, however, as indicated by the two-type-meter method were identical for both series of tests." To elaborate somewhat on these results a detailed comparison is given in Table 2, using the Winter-Kennedy piezometer system as a parameter. The data presented show that the two-meter method properly accounted for the presence or absence of the

[15] Research Engineer, Ateliers Neyret-Beyler and Piccard-Pictet, Grenoble, France.

trash racks as identical corrected discharges were obtained in either case.

TABLE 2 COMPARISON OF TESTS WITH AND WITHOUT TRASH RACKS

| | Unit with trash racks and without false roof | Unit without trash racks and without false roof |
|---|---|---|
| Type 3 current meter........ | $Q_3 = 5006 \times D^{0.4950}$ | $Q_3 = 5021 \times D^{0.4950}$ |
| Type 1 current meter ....... | $Q_1 = 4964 \times D^{0.4950}$ | $Q_1 = 4989 \times D^{0.4950}$ |
| Difference in coefficients...... | 42 | 32 |
| Correction to type 3.......... | $3/2 \times 42 = 63$ | $3/2 \times 32 = 48$ |
| Corrected discharge equation. | $Q = (5006 + 63) \times D^{0.4950} = 5069 \times D^{0.4950}$ | $Q = (5021 + 48) \times D^{0.4950} = 5069 \times D^{0.4950}$ |

The comparison of the Gibson and current-meter tests on this unit shows a difference of less than 1 per cent. Certain corrections must be made to the Gibson measurements; according to Professor Thoma's paper[16] a correction of about 0.5 per cent is necessary in the case of Safe Harbor. After allowing for the difference in head, which was more favorable during the Gibson test, the two methods agree within 0.2 per cent for peak efficiency. The close agreement between the two methods on this unit is very remarkable.

It may be well to consider the Princeton experiments in greater detail, particularly the results given by Professor Moody in Table 1. His argument, in brief, is that inasmuch as the type-1 meter seems not affected by the turbulence or obliquity introduced by the jets (compare $V$ with $V_1$ in Table 1) and type 2 is affected, a correction applied to type 1 on the basis of the performance of type 2 is unnecessary and false. The results of these experiments at Princeton can be clearly shown graphically, and Fig. 3 is based on the original data put at our disposal by Professor Moody. Left- and right-hand meters are combined on the same plot; this is permissible since runs were made for each meter in both directions. It is apparent that turbulence as produced in the flume not only affected the type-2 meters, but also the type-1 meters. The average curves are drawn to show, as well as possible from the scattered points, the apparent average effects. Knowing the distribution of the crosscurrent and the meter ratings in oblique flow, the theoretical underregistrations for each meter type can be computed for the particular conditions of these experiments. This has been done for both types of meters and for the runs of 40 and 60 ft, see Fig. 3.

The agreement with the experimental data is naturally not perfect, nevertheless it is sufficiently close to show in a striking manner that given the distribution of crossflow and the oblique ratings of the meters, the results actually obtained could have been predicted surprisingly well. It was to be expected that the points for the type-2 meter should fall below the observed curve because the theoretical calculations could not take into account the effect of friction in starting the propeller after it had stopped. It seems of utmost importance to note that the trend of the curves is such that the expected ratio of underregistration of the two-meter types is approached as the velocity increases. Since this ratio is about 1 to 4 the results indicate that this ratio may be attained somewhere around 6 ft per sec. It is evident that all tests at Princeton were made within a velocity range where the jets produced an angularity sufficient to stall the type-2 meter; therefore, no proper results could be obtained. Although extrapolations are often dangerous, the trend of the results clearly indicates that the two-meter method would have been substantiated for higher velocities where the limitations of neither of the two meters are exceeded.

Professor Moody fears that, as a result of test errors inherent in each method, the correction applied may be too large, particularly when the correction is greater than the small difference between the oblique flow characteristics of type 1 and type 3. Professor Moody assumes an individual error for each type of 0.25 per cent and suggests an overall error for the two-meter method of $\pm 1$ per cent.

In the first place we must classify errors into two groups, one consisting of systematic errors inherent to the method, and a second group comprising accidental errors. If measurements with both meters are made by the same method, identical except for difference in pitch of the meter, we may safely assume that the systematic error affects the measurements with each type of meter by the same percentage and in the same direction. There

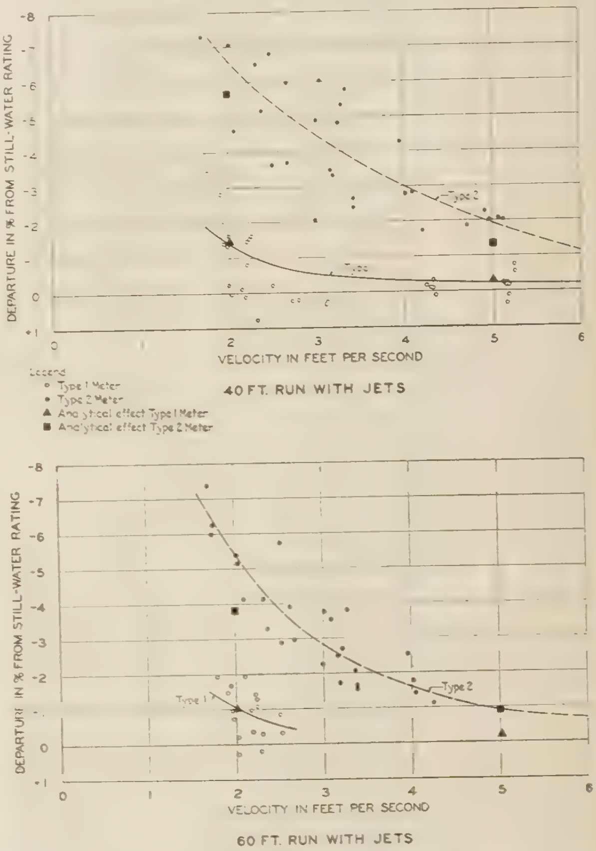


Fig. 3 Graphic Analysis of Princeton Tests

results an overall systematic error which is neither increased nor decreased by using more than one meter. On the other hand accidental errors have actually been determined for each individual group of tests, and it is not necessary to assume an error of 0.25 per cent as suggested by Professsor Moody. For the measurements made with each type of meter as shown on page 315, Table 4, of the paper, the accidental error or relative precision was found to be: $\delta_1 = \pm 0.054$ per cent.

We can now compute the accidental error for the two-type-meter method using type-1 and type-3 meters as at Safe Harbor, having pitches of 25 and 15 cm, respectively. We know that $\delta_1 = \delta_3 = \pm 0.054$ per cent. Hence the accidental error of the two-meter method is:

$$\delta = \delta_1 + \frac{15}{25 - 15} \sqrt{\delta_1^2 + \delta_3^2}$$

since $\delta_1 = \delta_3$

[16] "Concerning the Degree of Accuracy of the Gibson Method of Measuring the Flow of Water," Trans. A.S.M.E., vol. 57, 1935, paper HYD-57-4, pp. 203-211.

$$\delta = \delta_1 (1 + 1.5 \sqrt{2}) = \pm 0.17 \text{ per cent}$$

It is easy to see that the actual accidental error of ±0.17 per cent compares favorably with the assumed value of ±1.0 per cent given by Professor Moody.

As Professor Moody seems concerned about the error arising from using a correction which is larger than the difference between the two meters, it is of interest to compute the accidental error for the two-meter method using current meters of 15 and 30 cm pitch. In this case the discharge correction to the meter with the smaller pitch would be equal to the difference established by the two meters. Assuming the same relative precisions for the individual series as determined for the Safe Harbor tests, that is: $\delta_{15} = \delta_{30} = \pm 0.054$ per cent, the accidental error for the two-meter method would be

$$\delta = \delta_{15} + \frac{15}{30 - 15} \sqrt{\delta_{15}^2 + \delta_{30}^2} = \delta_{15} (1 + \sqrt{2})$$

$$= \pm 0.13 \text{ per cent}$$

It may be seen that the difference between the accidental errors, using a somewhat more suitable ratio of pitches than those actually used at Safe Harbor is only 0.04 per cent, which is indeed a completely negligible amount.

Efforts to bring the oblique-flow characteristics of propeller meters closer to the cosine or ideal meter registration by means of shrouding are interesting and commendable. All results so far available, however, have shown that little hope may be entertained for success. Although the performance is improved for angles up to 15 deg, the oblique-flow characteristics are seriously impaired for higher angles; in this range a definite and undesirable break occurs in the curve obtained when plotting underregistration versus angle of obliquity. Since under almost any field conditions for low head units obliquities in excess of 20 deg must be reckoned with, the use of one single type of shrouded propeller meter cannot be considered at the present time.

In order to show what may be expected of current meters without shrouding, the characteristics of a family of three-spoke, vane-type propellers is reproduced in Fig. 4. It may be seen that the ideal current meter for this family will have infinite speed as the pitch appears to be zero. From a practical point of view a pitch of 10 cm may be the lower limit at the present time.

Mr. Rogers seems to believe that the Holtwood tests cannot be compared with the field conditions because the effective obliquities were so much smaller at Holtwood than those encountered in the field. The underregistrations for the type-1 meter for the Holtwood laboratory tests and the field tests are given in Table 3.

TABLE 3 COMPARISON OF UNDERREGISTRATION

| Test no. | Type of test | Underregistration of type-1 meter, in per cent |
|---|---|---|
| 1 | Holtwood flume with stilling racks | −0.20 |
| 2 | Holtwood flume without stilling racks | −0.49 |
| 3 | S.H. unit with false roof and with trash racks. Meters in gate slots | −1.06 |
| 4 | S.H. unit without false roof and with trash racks. Meters in emergency gate slots | −2.09 |
| 5 | S.H. unit Without false roof and without trash racks. Meters in emergency gate slots | −1.60 |

A comparison of tests 4 and 5 in Table 4 shows that the influence of the trash racks is 0.49 per cent. If a test had been made on the unit with the false roof but without the trash racks, the underregistration of type 1 would have been in all probability close to (1.06 per cent — 0.49 per cent) = 0.56 per cent, that is a value almost as small as that of test 2 in Table 3. Obviously the underregistration would be slightly more for such a test; even with the false roof the approach conditions in the short intake could not have been so good as in the Holtwood flume under the conditions prevailing without stilling racks. It is believed that the results as obtained and as given in Table 3 show that the flow conditions in the laboratory flume and in the field are comparable.

In view of the current-meter tests at Eddystone, Mr. Rogers seems inclined to believe that propeller meters may overregister in turbulent flow. It should be borne in mind, however, that during these tests water was not measured by means of current meters but by a pitot tube, subject to inherent errors in turbulent flow. Losing sight of this fact erroneous conclusions will necessarily result.[17] Furthermore, if Mr. Kerr's conclusions were correct, that is, that the type-1 meter overregisters by 5 per cent instead of underregistering by 2 per cent, then the true discharge for the Safe Harbor units would differ by 7 per cent from the result obtained by means of the Gibson method.

Mr. Rogers thinks that the conditions in the field would necessarily be different from the calibration conditions, as at any given

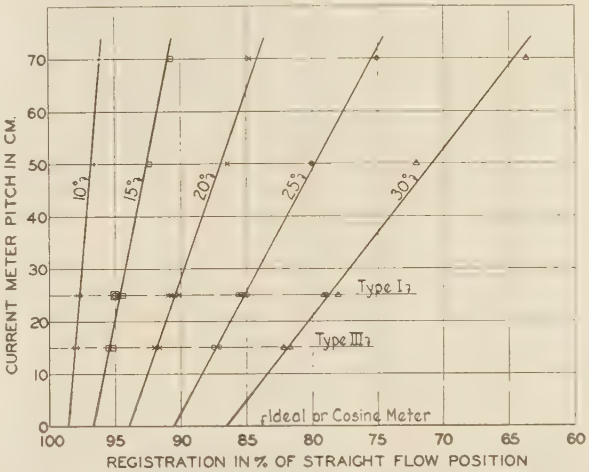


Fig. 4 Oblique Flow Characteristic of Propeller Family With Three Spoke Vanes of Convex Curvature and Straight Generatrix

time during the registration the obliquity and velocity across the face of the meters are subject to variations. It is believed that the tests carried out by Mr. Hackett and described by Professor Moody substantiate the belief that uneven velocity distribution across the face of meter propellers is of no concern. Since Mr. Hackett mounted the meters on a swinging frame oscillating to and fro, and since the rate of acceleration or deceleration is dependent upon the distance from the pivot around which the frame was oscillating, the velocities could naturally not be uniform over the entire area of the meter propellers.

Professor Moody reports that these tests showed no effect on the meter registration for the variations in obliquity across the face of the blade. At the same time the analysis of Fig. 3 of the Princeton tests with water jets as well as the oscillation tests carried out by Yarnell and Nagler tend to show that no abnormal conditions may be expected in the field.

The saving of the integration method over the point method is not 75 per cent as interpreted by Mr. Roberts, but 87.5 per cent as may be surmised from a statement on page 315. Of course, in using two types of meters, the saving is hardly more than 75 per cent over the old method employing only one-meter type and the point method. It should be borne in mind, however, that once the effective obliquity for any setting is known, only one type of meter need be used for further tests and the necessary overall correction can be made without using a second meter type. For

[17] This the author pointed out in his discussion of a paper by S. L. Kerr which will appear in a later issue of the Transactions.

future tests at Safe Harbor it would appear hardly worth while to use two types of meters as the corrections to type 1 or type 3 are known sufficiently accurately that at least 50 per cent of the effort of testing can be saved.

In answer to the specific question by Mr. Roberts regarding the magnitude of changes in flow during one test run, the writer would like to refer to page 315, Table 4, where the consistency or the average departure of a single run was computed to $\pm 0.24$ per cent. This is an extremely low value, considering that all accidental errors of the current-meter method and errors arising from the piezometer readings are included. How much of this value is really due to the change in flow is impossible to say.

Attention may be drawn simply to one statement made by Messrs. White and Rheingans to the effect that propeller meters did overregister as much as 50 per cent. The writer can hardly believe that Messrs. White and Rheingans have lost sight of the fact that Yarnell and Nagler did not try to measure water by means of current meters but simply determined the relative indications of various types of meters at different locations of a flume cross section using the discharge or mean velocity as determined by a weir as a parameter. Neither could it be assumed that they did not realize that the apparent overregistrations were not overregistration at all because the meter locations chosen by Yarnell and Nagler for these particular tests were in the high velocity jets caused either by blocking part of the flume by means of a submerged weir or by a vertical obstruction.

The contribution of Messrs. White and Rheingans, however, serves one useful purpose in recalling the current-meter tests at Massena in 1914. It may be well to study the equipment and methods used in these tests to see how much progress has really been made.

The writer wishes to thank Professor Moody and Messrs. Rogers, Roberts, and Danel for their respective criticisms, suggestions and new data made available. The serious thought given by these contributors as well as the experimental effort made at Princeton are the more appreciated as only through a common effort of many engineers may advancement in the art be possible.

# Locomotive Tractive Effort in Relation to Speed and Steam Supply[1]

H. S. Vincent.[2] The title of the paper expresses precisely what the authors propose. The usual tractive-effort formula gives the relation between two variables, the speed and the tractive effort. The authors have introduced a third variable, viz., steam supply.

The exigencies of design limit the supply of steam which the boiler can furnish and the necessities of transportation govern the speed which the locomotive can attain. Locomotives are not built primarily to develop thermal efficiency, a desirable asset but incidental to operating efficiency, or the maximum return for the money invested.

As a rule, a locomotive is designed to meet definite operating conditions, involving the overcoming of known resistances such as speed, grade, and curvature. These tax the capacity of the locomotive; otherwise, a less powerful unit would suffice.

A designer is primarily concerned with the tractive effort that the locomotive will deliver under normal operating conditions. The writer begs to differ with the authors of the paper and asserts positively that there is such an entity as "maximum tractive effort" and in addition, there is a "family" of lesser tractive efforts which may be developed ad lib.

[1] Published as paper RR-57-2, by E. G. Young and C. P. Pei, in the August, 1935, issue of the A.S.M.E. Transactions.

[2] East Harwich, Mass. Mem. A.S.M.E.

The maximum tractive effort for any given speed, is that delivered by the locomotive when its boiler is furnishing to the cylinders the maximum weight of steam of which it is capable, providing the cylinders can utilize it. Every locomotive boiler has a very definite maximum steam capacity as has been clearly demonstrated by L. H. Fry.[3] This type of operation is very inefficient thermally but may at times be necessary to meet certain exigencies of transportation.

There is a definite weight of steam which a locomotive boiler can deliver continuously to the cylinders. This is contingent upon the firing of a definite weight of fuel per square foot of grate surface per unit of time. Cole proposed a firing limit of 120 lb of bituminous coal per sq ft of grate area per hr. Modern practice tends to reduce this to 100 lb or even less. Under such conditions of firing and steam generation, the boiler efficiency will range from about 55 to 60 per cent. This is what the writer terms normal operation, and the tractive effort which the locomotive will deliver at such boiler operation is termed normal tractive effort. This is the criterion by which the locomotive designer measures his product.

The authors have devised a set of equations based on data obtained from a test of two Pennsylvania locomotives of similar design, which may be used to estimate the tractive effort of any locomotive by making certain adjustments involving cutoff, mean effective pressure, and weight of steam per revolution. The validity of these equations is contingent upon the accuracy of the basic data.

It is evident from a study of the example given in the paper, that there are at least ten operations necessary for establishing the tractive effort for each increment of speed, besides necessary references to charts. However accurate such a system may be, it involves too much labor to make its use general.

The writer has published[4] a method of determining the tractive effort of locomotives. The equations given in this method are also based on data from Pennsylvania tests, but the data have been generalized so that they do not involve the specific determination of cutoff or mean effective pressure as such. The tractive-effort equation is

$$T_s = \frac{1.95\, P_1 M}{1 + (36.66 MS/Hv)}$$

where $T_s$ = indicated tractive effort, lb; $P_1$ = boiler pressure minus 10, lb per sq in.; $M$ = the engine constant, $d^2s/D$; $S$ = lineal speed of the locomotive, mph; $H$ = the normal steam production of the boiler available for the cylinders, lb per hr; $v$ = specific volume of steam at $P_1$ and 100 deg superheat.

This equation gives only the hyperbolic portion of the tractive-effort curve, which in its entirety consists of a straight line, a hyperbola, and a connecting or transition curve. The complete derivation of the equation is given in the published article[4] and demonstrates its rational or semirational character.

In Fig. 1 of this discussion are shown curves of tractive effort as derived from the authors' formulas compared with those derived from the writer's equations, based on a locomotive having the dimensions given in the authors' example. The full-line curves in Fig. 1 of this discussion are copied exactly from the Fig. 8 of the paper. For steam flow of 30,000 lb, 40,000 lb, and 50,000 lb per hr, there is little difference between the curves constructed by the two methods. For steam flow of 60,000 lb per hr, there is a wider difference amounting at the maximum to about 7 per cent. The coincidence of these curves indicate that the formulas have a common base.

[3] "A Study of the Locomotive Boiler," by L. H. Fry, Simmons-Boardman Publishing Company, New York, N. Y., 1924.

[4] "Ratios of Modern Locomotives," by H. S. Vincent, *Railway Mechanical Engineer*, vol. 108, November, 1933, pp. 390.

The authors have assumed that the proper determination of a tractive-effort curve involves finding the cutoff and mean effective pressure for every increment of speed. In other words, the cutoff is viewed as a means of varying the mean effective pressure, instead of being considered as a measuring device for keeping a constant weight of steam flowing through the cylinders per

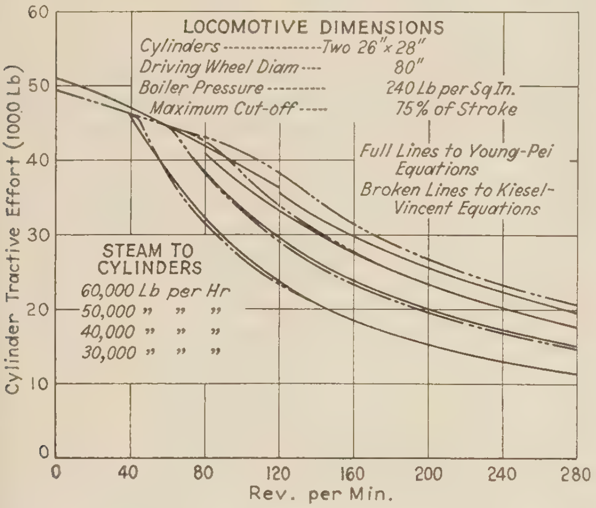


Fig. 1

unit of time. This latter consideration is the ideal toward which locomotive designers should work throughout the whole speed range but its attainment involves the use of a better system of steam distribution than that commonly in use.

A. Giesl-Gieslingen.[5] The writer calls attention to a paper[6] by A. I. Lipetz which was presented at the 1934 Annual Meeting of the A.S.M.E. in which was given a method for establishing a performance curve for any given steam locomotive of conventional design. The writer might refer to it as the curve of efficient maximum performance. Messrs. Young and Pei oppose the use of any single performance curve, or speed-pull curve, such as worked out by Lipetz and others, on the premises that they are not sufficiently defined and that such a curve does not possess a significant meaning. Therefore, the authors maintain, a series of speed-pull curves should be used, and have shown in this paper how to calculate these and how to find the corresponding steam consumption. Personally, the writer sees no conflict whatever between these methods and believes that one supplements the other. A diagram should make this clear.

Fig. 2 of this discussion, corresponding approximately to Fig. 8 of the paper, gives for a certain locomotive tractive-effort curves for constant cutoffs (light full lines), tractive-effort curves for constant steam flow to the cylinders (light broken lines), and a single curve of performance tractive effort (heavy full line) such as may be obtained by the Lipetz method.[6] Without the heavy line, that is with the results from the authors' method alone, complete information is given as to what the locomotive will do under various loads, but it is not known just how high the locomotive can be strained. The maximum steam generation might be estimated from boiler dimensions, but the authors do not deal with this phase of the subject. Therefore, the heavy line is desirable since it shows the approximate maximum performance which efficiently may be obtained. It is known, from the derivation of the Lipetz curve,[6] a slight increase in tractive effort can be obtained, at least at some distance from zero speed, if the boiler is forced to the limit. If the tractive-effort curve developed by H. S. Vincent[4] were used then it would be known that we are close to the absolute limit of performance that can be expected. But if the locomotive is not strained beyond the Lipetz curve, then we shall always work safely and efficiently.

The authors' method can be used to check the steam consumption established by the Lipetz method. If it is desired to control operation by a valve pilot, the combined results from the chart can be used to establish the relation between cutoff and speed for

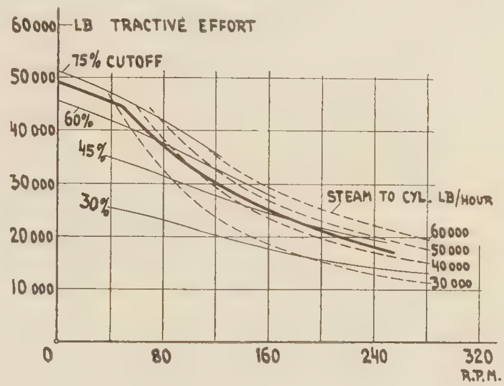


Fig. 2

the valve pilot. The writer therefore believes it is evident that the Lipetz method and the method presented by Young and Pei supplement each other.

The writer also wishes to discuss a point in which the authors' method should be corrected. For this purpose, Fig. 3 of this discussion has been drawn wherein a representative indicator dia-

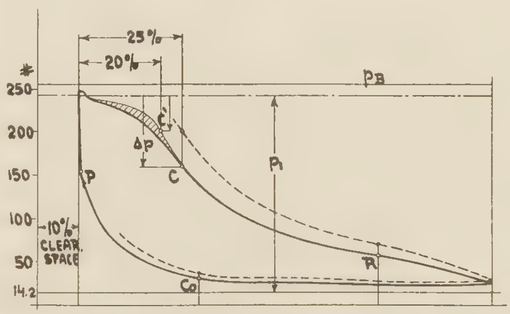


Fig. 3

gram is shown by a heavy line. This diagram is taken from a 2-8-4-type locomotive with 28 × 30-in. cylinders and 14-in. piston valves, at 25 per cent cutoff and 222 rpm corresponding to 40 mph. Fig. 4 of this discussion reproduces, in part, the authors' Fig. 4. The authors recommend this later figure for establishing the steam consumed per revolution for various cylinder sizes.

Assume that the indicator diagram in Fig. 3 of this discussion corresponds to a cylinder of the volume $V_1$ which the authors use as a basis for comparison. The steam consumed per revolution is then a certain unit quantity, as represented by the point encircled in Fig. 4 of this discussion. Now assume that we have a cylinder of half the unit volume, working at the same cutoff

[5] Mechanical Engineer, New York, N. Y. Assoc-Mem. A.S.M.E.

[6] "Horsepower and Tractive Effort of Steam Locomotives (Locomotive Ratios)," by A. I. Lipetz, Trans. A.S.M.E., vol. 55, 1933, paper RR-55-2, pp. 5–42; and vol. 56, 1934, paper RR-56-6, pp. 923–933.

and with all conditions equal. It would be expected that such a cylinder would consume one half of the unit of steam per revolution. The light broken line in Fig. 4 of this discussion corresponds to this expectation. However, the authors' figures as represented by the heavy full line show a consumption of 65 per cent of the unit, that is, the small cylinder would consume 30 per cent more than expected. On the other hand, it is known that the authors assume the mean effective pressure to be independent of cylinder size, in other words, the indicator diagram in Fig. 3 of

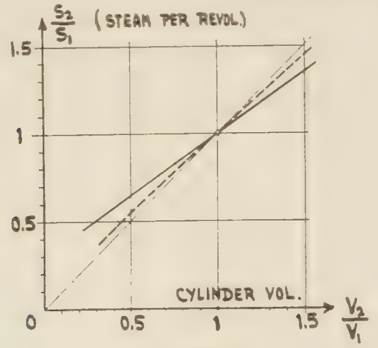


Fig. 4

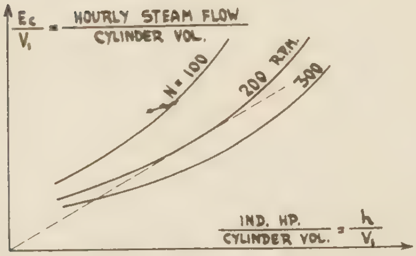


Fig. 5

this discussion will be valid for any size of cylinder. This will be true if valve gear and steam passages are proportioned in a fixed relation to cylinder volume, so that items such as throttling effect and back pressure will be the same, no matter how large the cylinder may be.

Due to the last mentioned assumption on the part of the authors, the indicated horsepower will be directly proportional to cylinder size. In the writer's example, indicated horsepower would be one half of that for the unit cylinder, and therefore, the half-size cylinder would consume 30 per cent more steam per horsepower-hour than the unit-size cylinder.

A smaller cylinder will have a higher specific steam consumption only because it will have a greater loss from leakage and cooling since the linear dimensions and the surfaces diminish at a lesser rate than the volume. However, it seems improbable that the difference should be as great as previously indicated. A check can be made as follows:

First, the formula

$$C_{i_2} = C_{i_1} \frac{0.3 + 0.7\ (V_2/10.45)}{0.3 + 0.7\ (V_1/10.45)} \frac{V_1}{V_2} \cdots\cdots\cdots [A]$$

which has been developed from the authors' paper and gives the steam consumption per indicated horsepower-hour $C_{i2}$ for the cylinder 2 if we know the steam rate $C_{i1}$ for cylinder 1 and the respective cylinder volumes. Suppose cylinder 1 measures 29 × 32 in., and cylinder 2 measures 24 × 28 in. Then a steam rate is obtained which is $16^1/_2$ per cent greater for the smaller cylinder 2. The writer will try to determine whether this result is possible. We can be sure that the excess in steam requirement due to cooling and leakage for cylinder 1 will not be more than 30 per cent of the steam requirement which would be obtained if there were no cooling nor leakage. It may be further assumed that the excess steam requirement due to these causes is proportional to the relation between surface and volume of the cylinder. This relation is 2.23 for cylinder 1 and 2.62 for cylinder 2, that is, 17 per cent more. Therefore, the excess steam requirement for cylinder 2 due to cooling and leakage will be 30 times 1.17 or 35 per cent. In other words, a cylinder which is about 40 per cent smaller by volume might consume 4 or 5 per cent more steam per horsepower-hour than the cylinder forming the basis of comparison.

This result is supported by tests. For instance, the German State Railways found that a three-cylinder locomotive consumed 4 per cent more steam per indicated horsepower-hour than an otherwise identical two-cylinder locomotive, because the volume of the individual cylinders is about 33 per cent smaller in the case of the three-cylinder arrangement.

Now, according to this result, the heavy broken line in Fig. 4 of this discussion may be drawn as representing approximately the steam requirement if valve gear and steam passages are of constant proportions relative to cylinder volume.

For the authors' line of steam requirement, there remains no other explanation than that the smaller cylinders had larger valve openings and had therefore fuller indicator diagrams for a given cutoff. This is actually the case, as shown by a closer investigation of the locomotives from which the authors selected their data. Therefore, the steam requirement per revolution is greater than that corresponding to the heavy broken line, but the mean effective pressure is also greater, which the authors neglected. This condition requires correction, and formula $A$ will assume a different form.

The curves could be corrected for mean effective pressure so as to correspond to the authors' curves of steam requirement per revolution. However, the writer would rather correct the curve for steam requirement as shown by the heavy broken line, because it would complicate matters unnecssarily by assuming that smaller cylinders have relatively larger steam passages, even though this was often the case in older engines, more particularly.

Further, the writer would like to suggest that the mean effective pressures be based upon boiler pressure rather than upon admission pressure. Since the authors have used boiler pressure for the calculation of steam flow, it would be logical and more correct to do the same in computing mean effective pressure. Either boiler pressure or admission pressure should be used in both cases, but not boiler pressure for the one computation and admission pressure for the other. In a method of this character, which neglects an item as important as steam temperature, for instance, boiler pressure seems a sufficiently accurate basis, and adds to simplicity.

The writer agrees with the authors that their method is the most direct one that can be used for the purpose. Certainly the method of figuring performance on the basis of steam supply and specific consumption per indicated horsepower-hour is what might be termed an indirect one. Although it is perhaps a matter of personal preference which way should be chosen, the writer believes that the specific steam consumption is an extremely practical yardstick since most engineers are more familiar with it than with such a quantity as steam per revolution. Whatever result is obtained from the application of the authors' direct method most engineers will check this result by ascertaining whether or not steam consumption per horsepower-hour thus obtained is a plausible figure. Also, steam consumption changes much less over the whole working range of the locomotive than do the

ratios used in the direct method. It is a special feature of modern well-designed locomotives that steam consumption fluctuates far less with speed and cutoff than it did in locomotives of older design. Therefore, steam consumption becomes more and more useful as a yardstick for approximate calculations.

Extremely helpful charts can be obtained by plotting the hourly steam requirement per unit of cylinder volume against indicated output per unit of cylinder volume as shown in Fig. 5 of this discussion. Such a chart may be computed from the cylinder having the volume $V_1$ which the authors used as a basis, and is then approximately valid for any reasonable cylinder size. The tangent of the angle formed between the abscissa and any line drawn from the corner of the chart to any point in the chart represents the steam consumption per horsepower-hour for that particular point. This method of plotting was introduced by the late Mr. Strahl in Germany about ten years ago.

Before closing, the writer would like to discuss in general methods for evaluating such items as locomotive performance and steam consumption. He believes that three methods are necessary. The first should be a simple method for establishing a curve of reasonable maximum performance, such as the one advanced by A. I. Lipetz. The second should also be a simple method for expounding conditions outside of that so-called reasonable maximum performance. This method is the one advanced by the authors, supplemented by studies of the boiler. These two methods serve every-day requirements. Therefore, they must be as simple as possible, and they need not be too accurate or universal. It is sufficient if they give reasonably correct results merely for the types of locomotives in general use at a given period, for instance, today. Consequently, these methods can be essentially empirical in so far as this helps to achieve simplicity, and the writer believes that it does not matter much whether they be termed "direct" or "indirect" methods, as long as they serve their purpose and save time in their application.

The third method, however, should serve the purpose of finding new refinements in engine design. Therefore, it must be essentially scientific and strictly analytical, and it must avoid indirect approach of the subject. The indicator diagram must actually be constructed and all phases of the working process must be investigated. This is the method which is still being neglected. It is usually feared that there are not yet enough data for the proper application of such a method, but this is not the case. The data are here, but they are usually hidden and unexploited. Fortunately, the significant feature of scientific methods is that they can rely on a few good tests as a basis, instead of referring to the average of a larger number of tests.

The writer believes that there are three major possibilities for improving locomotive thermal efficiency and performance without increasing maintenance. These are (1) improved valve gears of the poppet type, (2) utmost reduction of back pressure through a scientific front-end design, and (3) moderately higher working pressures. However, the attainable economies cannot be ascertained unless the indicator diagram and the thermodynamic working cycle are analyzed scientifically, this being the only way of evaluating opportunities and their limitations prior to spending money on tests of tentative designs. Such studies will pay high dividends. The writer feels that the new Research Division of the Association of American Railroads would be the proper body to take up that subject among others. As far as the boiler is concerned, air preheating certainly offers the greatest opportunity.

Incidentally, the writer would like to stress that high-speed locomotives will have to be developed very carefully because, as Lipetz' paper[6] shows, the performance curve of conventional locomotives at more than 250 rpm leaves much to be desired.

The American steam locomotive has the highest earning capacity among the steam locomotives of the world. Rugged, strong and simple design, high availability, and fine operating methods are largely responsible for that. However, we are somewhat behind others in steam and fuel efficiency, and in this respect have much to accomplish.

Kenneth S. M. Davidson.[7] In the writer's opinion Messrs. Young and Pei have made the most important contribution of recent years to the literature of the subject. This paper presents a direct logical method of estimating the performance of locomotive engines. But its true significance lies less in the details of that method than in the fact that it attacks the problem from the same straightforward point of view that has clarified performance estimates of practically all other kinds of power units. Two short sentences suffice to state this point of view:

1 To mean anything, a performance estimate must be accompanied by a definite statement of the operating conditions for which it is made.

2 In a complete and adequate method for estimating performance, every effort must be made to isolate the effects of individual variables and to make each constant dependent upon the effect of a single variable.

Even a casual glance at the methods in common use, or others recently suggested, for estimating locomotive performance shows how completely they fail to meet these simple specifications. It is not enough that a method shall give satisfactory answers when proper constants are inserted. Unless the true meaning of each constant stands out clearly, so that some reasonable judgment can be formed of its probable behavior when the dimensions or proportions of the machine are altered, the method cannot meet the needs of either designer or user. Although there have been several important developments in locomotive design in recent years, for example, the introduction of long-travel valve gears, neither the desirability of these modifications nor their probable quantitative effect on performance could be foretold by any of the existing methods of estimating. The quantitative effects have eventually found their way into the methods, it is true, but by the very roundabout procedure of working backward from tests (road tests for the most part), to determine new values for obscure constants not directly related to the modifications themselves, but embracing several other variables as well.

It is difficult to understand why those concerned with steam locomotives have been content for so long with the illogical methods they have used. There would be reason enough if a locomotive were radically different in nature from anything else. But it is not, and there never has been any sound reason for supposing that it could not be analyzed by the straightforward steps commonly adopted in dealing with all other kinds of power plants.

The most striking thing about the paper is that it refers to the engines, without considering the boiler. No more forceful means could have been adopted to emphasize what appears to be the authors' contention, namely, that boiler performance and engine performance are essentially separable. The writer has been convinced for a long time that, beyond the fact that they receive steam at certain rates and exhaust it at back pressures which depend only on the size of the blast nozzle, the engines are not interested in the boiler, and that the boiler cares nothing about the engines beyond the fact that all of the steam it generates (excepting auxiliary steam) must be returned to its blast nozzle. It is easy enough to think of many secondary ways in which the two parts of the machine might conceivably affect each other, but it is extremely difficult to find test data to show that any of them are important. One of the most plausible of these is the assumption that drafting is affected by differences in the rate of exhaust im-

[7] Assistant Professor of Mechanical Engineering, Stevens Institute, Hoboken, N. J. Mem. A.S.M.E.

pulses. There is very direct evidence to show that this does not happen. Fig. 6 of this discussion (the data are from Pennsylvania Railroad Bulletin No. 32) is a typical chart of boiler efficiency against firing rate. This is the kind of chart which Fry investigated at such length in his competent analyses of boiler performance.[8] Fry's procedure has been followed in plotting all tests, regardless of speed, on the same chart, but the points have been labeled with the speed at which each test was made. The points group themselves about a straight line thus bearing out Fry's view but, more than that, it is apparent that wide variations

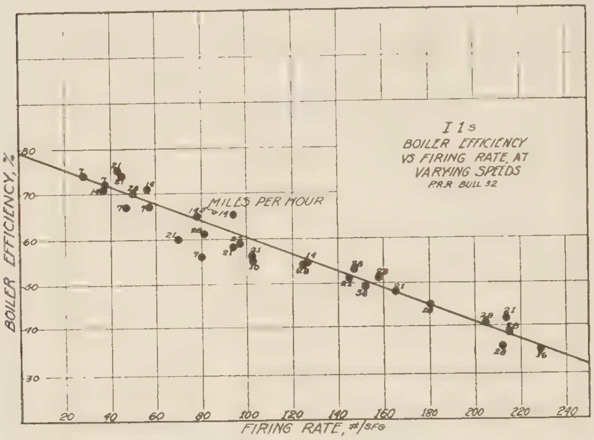


Fig. 6

of speed cause no systematic changes of boiler efficiency. If the variation in rate of exhaust impulses had any appreciable effect, it would certainly alter the boiler efficiency.

The idea of separating boiler and engine performances appears to be a fundamental, vital step in clarifying the whole problem. Fry assumed them separable in his work on the boiler and found no occasion, in that work, to refer to the engines at all. In reality, Young and Pei have carried on where Fry left off and, by clarifying the problem of the engines, as he clarified the problem of the boiler have done much to complete the task.

With Fry's method for boiler analysis and the methods of the present paper for engine analysis, a complete logical procedure for estimating locomotive performance and economy is available. It is entirely fitting that the present paper should omit any reference to boiler performance and yet it might have made a stronger general appeal if one or two cases had been worked out from beginning to end.

### Authors' Closure

The authors appreciate the kindly and pertinent criticisms of their paper, which seem to call for few comments.

Mr. Vincent's suggestion that we do not recognize a maximum limit is rather surprising in view of the material contained in the fifth paragraph of our paper stating three different limitations which might impose themselves. In a general analysis of the problem, however, this limit cannot be fixed; it must be applied with regard to a specific case. We quite agree that in general the boiler output will be the limiting factor, but we continue to doubt that this limit, as determined by evaluation of Mr. Fry's constants may be considered a practicable operating condition for any circumstances, and it remains for some one to determine how much the boiler is to be forced.

Dr. Giesl-Gieslingen makes a most useful comment in differing with us as to the slope of the curve by which the steam per revolution for smaller cylinders is to be determined. The data for the construction of this curve, in so far as they have been published, leave difficult gaps to be filled. We discovered in making the chart for speed-cutoff mep (authors' Fig. 7), the fact which he states, that the mep for some of the smaller locomotives was larger than would be expected, and considerable inconsistency was shown, which led us to adopt for this figure from the Pennsylvania K-4s, as stated on page 339, Vol. 57, of the 1935 A.S.M.E. Transactions. We cordially agree with our critic that compensatory alteration in Fig. 4 is preferable to attempting to change Fig. 7, even though there is thereby introduced some departure from rationality.

Professor Davidson agrees with our viewpoint on the legitimacy of separating the steam-production and steam-consumption processes. The most satisfactory procedure in estimating boiler performance is the proper evaluation of the constants in Fry's efficiency equation to take into account the quantity and quality of the fuel, the grate area, front end arrangement, combustion volume, heating surface, or such other conditions as affect the generalization of these coefficients. We hope at an appropriate time to present such an analysis.

[8] "A Study of the Locomotive Boiler," by Lawford H. Fry. Simmons-Boardman Publishing Company, New York, N. Y., 1924.

# Pitot-Tube Practice[1]

R. J. S. Pigott.[2] Referring to the statement quoted by the author, that the pitot tube overreads in turbulent flows, it may be desirable to clear up this terminology a little. In strict language, the pitot tube as discussed by Mr. Cole was not, in any of the devices tested, operated in anything except turbulent flow, since the Reynolds numbers are always very much above the critical value, beyond which viscous flow of any kind cannot subsist. Turbulent flow occurs around the pitot tube, in all three methods of measurement; that is, by the boom, in the venturi throat, or in the 12-in. steel pipe. It is solely on account of the fact that the flow is turbulent that the resistance, above the Reynolds critical number, is proportional to the square of the speed, instead of the first power as in viscous flow. It is believed that what is meant in this case by "turbulent flow" as used by Mr. Cole, is regular or eddying flow or, in other words, local alterations of the velocity traverse, and also the direction of the current. Such subsidiary conditions are due, in general, to disturbances such as elbows, gate valves, or any irregularities in the pipe ahead of the measuring device; are generally unsteady; and should not be confused with the normal internal turbulence of the fluid, which is never absent in speeds above the Reynolds critical value. Therefore, apparently what is meant by classing the venturi-throat flow as "smooth" is that these fortuitous local eddies are absent in this case.

As a matter of fact, they were also largely absent in the 12-in. steel pipe, as indicated by the relatively undisturbed symmetry of the velocity traverse. Indeed, it is these fortuitous disturbances of flow in which we are chiefly interested, in so far as the behavior of the pitot tube itself is concerned.

As the writer understands it, the coefficient of a pitot tube, as used in water-water studies, is the ratio of the pitot velocity to true velocity (any reading) and the pipe factor is the ratio between the mean velocity (as represented by the flow rate divided by pipe area) and the maximum velocity at the center of the pipe. From theoretical considerations, and also from the enormous number of velocity traverses which have been made, it is obvious

[1] Published as paper HYD-57-8, by E. S. Cole, in the August, 1935, issue of the A.S.M.E. Transactions.

[2] Staff Engineer in Charge of Engineering, Gulf Research and Development Corporation, Pittsburgh, Pa. Mem. A.S.M.E.

that this latter ratio ought to be 0.50 in the viscous region, with which we are seldom dealing in any kind of water flows, and should continuously increase up to very high Reynolds' number, in which case it becomes 0.95 or even higher in the case of air flows.

The Bureau of Standards' and other tests on nozzles indicate that the value is as high as 0.99 for high gas speeds. It is noticeable that in all these very high Reynolds' number cases, the velocity traverse is almost absolutely flat, just as shown on the venturi-meter throat by Mr. Cole. If this understanding is true, then we should expect that the coefficient or constant of the pitot tube is actually constant for any design if it is reading true kinetic head and true static, but the pipe factor should increase with Reynolds' number in any given pipe. However, the coefficients as given by Mr. Cole for the 12-in. pipe, both corrected and uncorrected, show a decrease with increase of velocity, which in this case is the same thing as an increase in Reynolds' number.

At first glance, it would therefore appear that the behavior of the tube is out of line with theory. However, the writer does not believe this is the case at all, but is due to a condition which is apparently not yet clearly recognized, that is, just what the projected area of the tube rod or support does to the readings. It is the writer's opinion that neither a complete correction for the full projected area, as affecting the mean velocity, nor an omission of this correction, is proper.

A brief consideration of the physical conditions around the tube indicates that it ought to be somewhere between these two values, and that the value will vary with the position of the leading and trailing tubes relative to the body of the rod, and also with the rod shape. It is obvious that the leading tube, in the cases of Figs. 4, 5, and 6 of the paper cannot be in any way affected by the shape or size of the tube rod inasmuch as the impact reaches the opening before any change in stream cross section has taken place.

The kinetic head therefore must represent the true velocity regardless of the shape or size of the tube rod. This condition is even true of the heavy-duty rod, the dimensions of which are shown in the author's Fig. 29. Therefore, any variation of the coefficient from what would be expected by simple theory, must be traced to the static tube which has its opening perpendicular to the flow of the stream or completely trailing, as in the Cole and other similar tubes.

Obviously, in Fig. 6 of the paper the trailing tube is reading static in a region which has been affected by the reduction of area due to the body of the tube. Reconversion of velocity to static head is incomplete and the static is lowered. It is rather difficult to say how much it is lowered because the increase of velocity of the stream past the support of the tube may have very little effect at the point where the tube tip is located. In the case of the tubes shown in Figs. 5 and 6 of the paper, the body of the tubes can have very little effect, if any, upon the static readings, because even the static readings in this case are upstream from any disturbances or changes of velocity caused by the tube rod. There is ample experimental evidence to show that these tubes do not show the effect of support obstruction.

It is obvious that the only correction for change of area in the case of the author's Figs. 5 and 6 should be for the area of the nose of the tube only, and not for the rod supporting the tube. In the case of the author's Figs. 6 and 22, the correction can only be a part of that due to the increased velocity past the body because disturbances of this sort are very largely local and the velocity of the liquid passing the tips of the tube will be affected chiefly by the change of section in the narrow portions of the support in this region, and very little by the main body of the support.

As has been mentioned previously, since the velocity traverse in the pipe changes with speed, viscosity, roughness, and absolute size, it should be expected that there would be a change of pipe factor, as shown in Prof. Pardoe's tests on different pipe sizes independent of the tube coefficient proper.

The writer believes that the change of overall coefficient is due much more to diameter and roughness conditions, for the University of Pennsylvania tests, than to the tube rod, although this may still be quite perceptible and will certainly vary with the actual shape of the structure. In the case of the Cole tube, in which the trailing orifice is a noticeable distance downstream from the body of the tube, and fairly close to the main body of the rod, it is quite possible that incomplete reconversion of the increased velocity, opposite the body of the tube, should somewhat lower the static reading, and this effect would be larger with increased velocities. If this is true, the decrease of overall coefficient with increasing velocity is easily accounted for.

Some years ago, the writer had tests made on reversible tubes (impact and trailing) very similar in body structure to the heavy-duty tube shown in Fig. 29 of the paper. These tubes gave depression of the static by the trailing tube to the extent that the apparent head was reading from 15 per cent to 20 per cent high. The writer believes Dr. Moss of the General Electric Company, could provide considerable test data on this subject, as he was forced to work it out in connection with high-speed air streams. The writer is of the opinion that Dr. Moss reached some very definite conclusions as to the effect of body proximity on the reading of the tube.

The writer does not believe it is safe either to neglect the area correction, or to assume that the body of the rod acts as a complete obstruction to change the velocity at the tube. The true answer can only lie in between these two values. The variation in results obtained in tests of the different laboratory set-ups tends to corroborate this hypothesis.

There is general agreement that the normal coefficient of the pitot tube without trailing downstream openings, when reading kinetic and static heads correctly, is practically unity and that all values of coefficients less than 1.00 are traceable, not to the tube, but to the situation of the tube in its surroundings. Under these circumstances, it would be expected that the coefficient of the tube, as tested on the boom in still water, ought to be substantially 1.00 throughout, provided there is no alteration of the static reading by the position of the trailing orifice, and that in the 16-in. venturi throat, the overall coefficient, which is the product of the tube coefficient and the pipe factor, ought to agree exactly with the ratio of mean velocity to maximum velocity, as shown in the traverses in Fig. 12 of the paper. The coefficients given for the 12-in. pipe do agree relatively closely with the corresponding velocity ratios given in the traverse in Fig. 12 of the paper, the differences (the writer believes) being largely traceable to the trailing tube being in a position to read slightly lower static than the undisturbed value, with no obstruction.

One condition of the tests which makes it a little difficult to develop a full hypothesis of the behavior of the pitot tube as actually installed, is that all of the tests were made on water, and with relatively small ranges of Reynolds' number.

To get a complete knowledge of the pitot-tube behavior, it would be necessary to make tests on liquids with very much higher viscosity, and also to correlate with tests on air and other gases, so as to get a very large range of Reynolds' number, as has been done in the cases of the disk orifice, the venturi tube, and the nozzle. In spite of the foregoing differences of opinion as to the causes of some of the variations of coefficients, the writer wishes to support the author's position, namely, that there is plenty of evidence to show that the pitot tube has an easily determinable and reliable coefficient, and that the device is inherently just as accurate as any of the other primary devices now used, provided it is properly installed and handled. There

is no question that, for the purpose for which the author largely uses this type of device, it is very much more convenient and less expensive than any of the other primary devices, such as the disk orifice and the venturi.

It must be said, however, that if the pitot tube is to take the position as a primary measuring device that it should occupy, a more complete study of its behavior in a wider variety of liquids than cold water, and in a wider range of pipe sizes and roughnesses, must be made in order to determine more completely those circumstances which alter the apparent coefficient.

It appears, from a study of all three of the principal primary devices, that the coefficient of the venturi tube and the rounded-approach nozzle is less than 1.00 almost entirely on account of pipe friction in the upstream cone; that the coefficient of the sharp-edged disk orifice is almost entirely a coefficient of contraction with little friction involved, and lastly, that the overall coefficient of the pitot tube, placed on the axis of the pipe, is largely a question of the normal velocity traverse in the pipe, and the coefficient of the tube itself, as determined by the position of static openings.

Frank H. Rogers.[3] Mr. Cole's paper is a very interesting résumé of the research work over a long period of years on the so-called "combined type" of pitot tube. Most of the test results shown in the paper were made on the tube shown in Fig. 6,

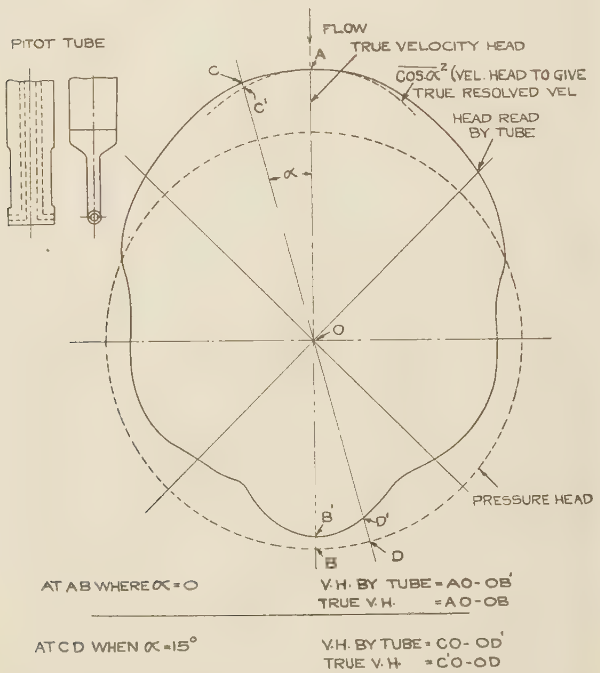


Fig. 1 Polar Diagram Readings of Combined-Type Pitot Tube Turned at Various Angles to the Direction of Flow as Compared to the Pressure Head

called the "reversible type" as the dynamic orifice and pressure orifice are 180 deg apart so that readings may be checked by turning the tube 180 deg.

From the results of these tests, Mr. Cole concludes that turbulence has little, if any, effect upon the form of pitot tube shown in Fig. 4 as the coefficients obtained in flowing water in a 12-in. pipe, in flowing water in the throat of a venturi meter, and by still-water rating agree within practical limits. Mr. Cole also concludes that angularity of flow in normal pipe lines is not as great as has been claimed as the tests he made in the 12-in. pipe showed angularity of not more than 5 deg.

The summary of the results as given in Fig. 25 of the paper show, for the flow conditions of these tests, very good agreement of the coefficients obtained in the 12-in. pipe, at the throat of the venturi meter and by the still-water ratings, the maximum variation between these three methods of calibration being about 1 per cent.

In these tests, however, the flow conditions in the 12-in. pipe should be almost ideal. The gaging section was located 38 diameters from the nearest upstream bend, and baffles were used at this point to minimize disturbance in flow. The excellent symmetry of the horizontal and vertical traverses, as shown in Fig. 13 of the paper, proves that very smooth flow occurred, and very little angularity would be expected. These calibrations should, therefore, be reliable if this tube is used in small pipes under similar good flow conditions. If used in pipe lines of large size or in small pipes where some turbulence was present, the writer would expect to obtain a considerably lower coefficient.

This is due principally to (1) angularity of flow causes the dynamic orifice to read higher velocity than the cosine curve, and (2) angularity of flow causes a considerable increase in the suction action on the pressure orifice.

The first effect is small compared to the second as shown by the typical polar diagram readings, Fig. 1 of this discussion. For straight-line flow it is seen that the velocity head, *VH*, read by the tube is slightly greater than the true velocity head due to the suction which occurs on the pressure orifice at 180 deg from the dynamic orifice. For angular flow of say 15 deg, however, the velocity head read by the tube is considerably greater than the true velocity head due to the fact that the dynamic orifice reads slightly above the cosine² curve and the pressure orifice reads considerably below the true pressure. Thus, for an angular flow of the previously given amount, the coefficient of this type tube would be considerably reduced.

To give accurate results, therefore, this type of pitot tube should be calibrated under conditions of flow similar to the conditions in the pipe or conduit in which it is to be used. It is also recognized by engineers in this line of work that in large pipes angularity or turbulence is usually greater than in small pipes due to the less effective guiding influence of the walls in the former. Hence, the coefficient of a combined tube, determined for a small pipe, is not reliable when this tube is used in a large pipe.

The simple tube used in conjunction with piezometer openings in the pipe wall is subject to this same error, but to a much less degree due to the fact that the dynamic orifice overregisters only sightly for considerable angularity of flow and the wall piezometers give the correct pressure at all times.

As an example of these conditions, let us assume that the combined-type tube is calibrated in a pipe where the average angularity of flow is 10 deg. Then from Fig. 27 of the paper, this tube will give a velocity about 3.3 per cent higher than if no angularity existed. If this calibration is used in measuring the velocity in another pipe where the average angularity is actually only 5 deg, the tube would read only 1 per cent higher than in straight-line flow, which results in an error of —2.3 per cent.

If this same tube is used in another pipe where some turbulence exists and the average angularity is actually 15 deg, the tube would read about 6.3 per cent high, or an error, as compared with the calibration used, of +3 per cent.

Under these same conditions, if a simple-type tube is used in conjunction with wall piezometers, and this tube were calibrated in a pipe where the average angularity was 10 deg, the tube would

[3] Chief Engineer, I. P. Morris Division of Baldwin-Southwark Corporation, Philadelphia, Pa. Mem. A.S.M.E.

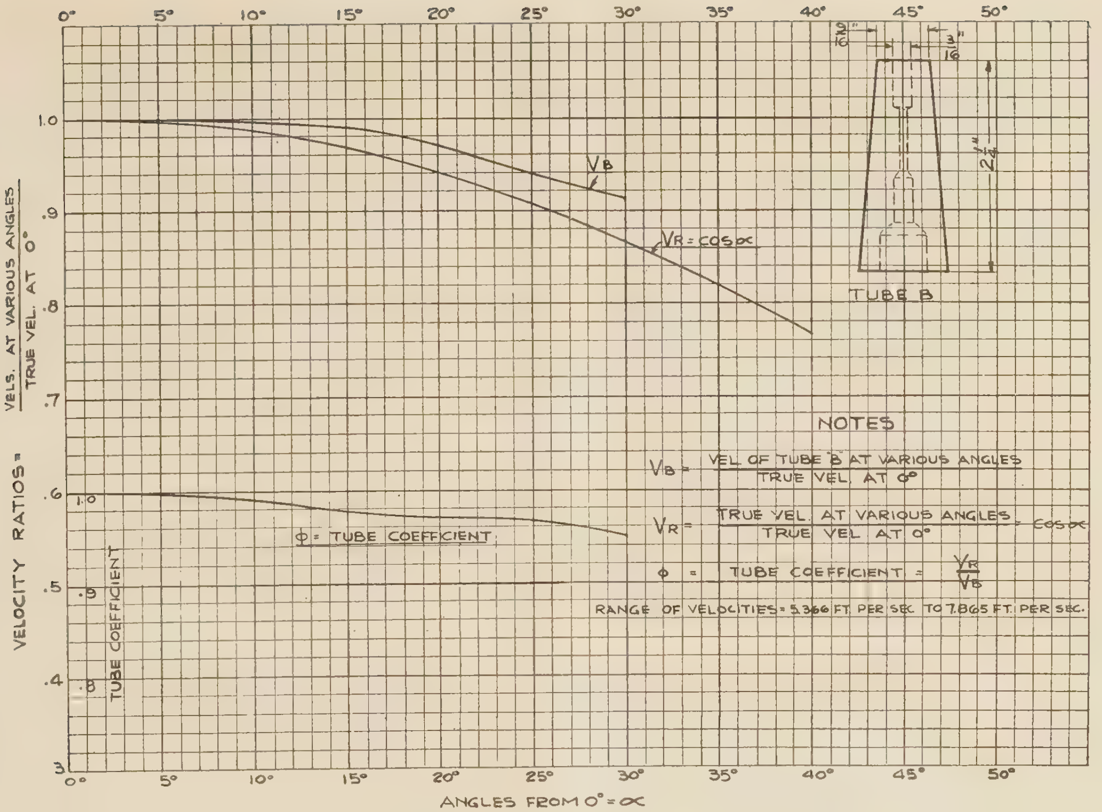


Fig. 2 Test Results of Pitot Tube at Various Angles

read about 1 per cent high. If this calibration is used in measuring the velocity in another pipe where the average angularity is actually only 5 deg, the tube would read about 0.2 per cent high, or an error of —0.8 per cent. If this tube were used in another pipe where the average angularity is actually 15 deg, the tube would read about 2.5 per cent high, or an error of +1.5 per cent.

These values for the simple tube are taken from a series of tests made by the writer in the flume of the Rensselaer Polytechnic Institute at Troy, N. Y., in 1910, in a still-water rating tank. A number of different simple tubes were tested for the effect of angularity of flow and the results of the tests of one of these tubes, known as tube *B*, is shown in Fig. 2 of this discussion. This type of pitot-tube nozzle is generally adopted for use in large pipes or penstocks.

It is evident that for the conditions of flow previously assumed, the possible error for the combined tube is from 2 to 3 times as great as for the simple tube.

The simple tube in connection with wall piezometers is generally used to determine the flow in large pipes or penstocks in hydraulic turbine tests. Its coefficient has a comparatively small range of values. For normal conditions of flow the coefficient may vary from 0.97 to 0.98. For extremely turbulent flow, such as sometimes occurs in large intakes of varying cross sections, the value of the coefficient may fall as low as 0.94 and for ideal flow conditions,[4] such as occur in a smooth small-diameter straight pipe at high velocities or at the throat of a venturi meter, the value of the coefficient will be very close to unity.

A number of tests have been made in large pipes to determine the coefficient of the simple tube by comparison with the flow determined by other accepted methods such as the weir. As an example, in the test of a 10,000-hp turbine at Niagara Falls, pitot-tube traverses were made in two 5-ft diameter penstocks, and the flow obtained from the tubes compared to the flow measured by a weir. These showed a coefficient for the pitot tube of 0.9763. Another test was made on a 6000-hp turbine at Shawinigan Falls where traverses were made by pitot tubes in a 9-ft diameter penstock, and the discharge compared to that measured by a weir. In these tests the value of the coefficient varied from 0.9761 to 0.9785. In view of these tests and a number of similar tests made by various turbine manufacturers, an average value of 0.9763 was selected by the Machinery Builders' Society and appears in their Standard Testing Code issued in 1917. It is believed that for the normal flow conditions usually encountered in large penstocks, this value of the coefficient is correct within about 0.5 per cent.

Due to the fact that in actual practice this coefficient is less than unity, it is apparent that angularity of flow, due to turbulence, is usually present in large pipes, and if angularity tests shown in Fig. 2 of this discussion are referred to, a coefficient of 0.9763 would be equivalent to an angularity of about 15 deg or slightly less. The small angularity of 5 deg mentioned by Mr. Cole in the paper may, therefore, be correct for small straight pipes free from bends, where very little turbulence occurs, but for the usual conditions in power developments where large-size pipes are used, it would appear that the average angularity of flow is considerably greater.

Mr. Cole presents some very interesting data in connection with the correction which should be applied to the coefficient due to the presence of the pitot tube itself. The curves in Fig. 18

[4] "Research Investigation of Current-Meter Behavior in Flowing Water," by S. Logan Kerr, Trans. A.S.M.E., vol. 57, no. 6, August, 1935, paper HYD-57-9, p. 295.

of the paper, show that for the combined tube used, some correction should certainly be made for the projected area of the pitot-tube rod. It is the writer's opinion that this correction for the rod is not necessary for the dynamic orifice of the tube, but is required for the pressure orifice, due to the fact that the area of the rod has little or no effect on the velocity conditions upstream from the rod. On the other hand, the pressure opening is located slightly downstream from the rod, and undoubtedly the effect of the rod on the area of the pipe at this point is appreciable and should be corrected as outlined in the paper.

The writer believes there is a field of application for both the combined tube described by Mr. Cole, and the simple tube. The field for the former is primarily in measuring the flow in relatively small-size pipes where the flow conditions are particularly good and where but little turbulence or angularity occur. In the case of small pipes, it would be very difficult at times to install wall piezometers which would give accurate readings. It is always necessary when using wall piezometers to have the surface of the pipe near the piezometers absolutely clean and smooth, so as to avoid eddies. When tests are being made in old pipes where the interior surface is rough and cannot be properly cleaned before the test, the use of wall piezometers would certainly involve considerable errors, and the combined tube is certainly preferable. For larger pipes where proper piezometers can be installed, and the inside surface made smooth, the simple tube will give the most reliable results.

John G. Sutton.[5] The following comments relative to the pitot tube apply particularly to drainage pumping plants but most of them are equally applicable to irrigation plants. It seems that the pitot tube should find wider use by engineers in private practice handling problems connected with drainage and irrigation plants and that these engineers should use this instrument regularly to determine the efficiency of plants under their supervision. The writer's experience with the use of the pitot tube extended over five years while employed by the U. S. Department of Agriculture on some investigations relative to drainage pumping plants.[6]

The pitot tube is a very accurate and dependable instrument for measuring flow of water in pipe lines. In the writer's opinion, the discharge of a pump can be determined with 97 per cent accuracy in a field test using a carefully rated instrument. In measuring the discharge of drainage plants the writer used the Tulane pitot tube developed by W. B. Gregory, which is mentioned in Mr. Cole's paper. The tubes used in this work were rated every year or two at the hydraulic laboratory of the Colorado State Agricultural College at Fort Collins, Colo., or at the U. S. Bureau of Standards, Washington, D. C. Ratings at both places were made by means of a car operated at different speeds on metal tracks over still water. At velocities ranging from 4 to 13 fps the coefficient was found to range from about 1 to 3 per cent above unity. Results were sometimes erratic at velocities below 4 fps. The coefficient of each tube did not materially change from year to year.

During investigations previously mentioned probably half of the tests were made on discharge lines where the pipe was flowing under vacuum. Under such conditions a small amount of air usually seeped into the instrument, necessitating frequent removal by means of a vacuum pump. The type of tube used, having air above the U-tube, performed very satisfactorily under these conditions. These instruments had considerable fluctuation in the water columns. An attempt was made to obtain a high degree of accuracy by averaging the fluctuations for each reading and making a large number of readings. The velocity was determined at ten points on rings of equal area. Eight readings usually were obtained at each of the ten points, or 80 readings were averaged to determine a point on the head-capacity or efficiency curve. By taking a large number of readings it was practicable to discard those that were inconsistent. With an experienced assistant, it was necessary to discard less than 1 per cent of the readings.

Horizontal and vertical ratings were made and averaged on pipes where the greatest accuracy was required, or where conditions were not favorable to obtaining accurate ratings by a single vertical rating. Under worse conditions the average velocities measured by the horizontal and vertical traverses did not differ by more than 6 to 8 per cent. After the relationship between average velocity for horizontal and vertical traverse was once established, only the vertical rating was taken in subsequent tests.

Some very interesting velocity curves were frequently obtained near bends in pipes. During some tests the velocity was about 12 to 14 fps near one side of the pipe, around 10 fps at the center, and 6 to 8 fps at the other side. In other pipes, symmetrical curves were obtained with the velocity at the quarter points exceeding the center velocity by as much as 2 or 3 fps.

No reduction in cross-sectional area of the pipe due to the pitot tube was considered necessary for the type of tube used, because of its L shape. The impact point in most cases on an average was about 6 in. in front of the vertical supporting tube, but varied with the size of the instrument. In the writer's opinion, this tube measured the velocity at the impact point and the reduction in cross section of flow was, under the conditions of the tests, too small to be considered.

It was always more convenient and sometimes necessary to insert the tube in the discharge pipe while the pump was not running. Stopping a pump at a drainage plant for a short period is ordinarily not objectionable.

Difficulty was experienced in taking ratings when the temperature was at the freezing point or below. Water froze readily in the small pipes of the pitot tubes and made accurate readings impossible. It was found necessary to arrange the pump test when the temperature was at least several degrees above freezing.

W. S. Pardoe.[7] A pitot tube when used as a measuring device is just as good as its calibration and as rods Nos. 162, 403, and 617, mentioned in the paper, were each calibrated in Professor Allen's laboratory under three different conditions, it would appear that these tubes have been calibrated very well and the results speak for themselves.

Tube No. 617 was also calibrated in the hydraulic laboratory of the civil engineering department of the University of Pennsylvania, in 12-in., 10-in., 8-in., and 4-in. pipes, giving the curves shown in Fig. 19 of Mr. Cole's paper. In Fig. 3 of this discussion, the writer has reproduced Mr. Cole's Fig. 15 showing the calibration of tube No. 617 by the boom method, as well as the calibration in a 16-in. venturi throat and in a 12-in. pipe at Worcester Polytechnic Institute. On this curve, the writer has placed the U. of P. calibration in a 12-in. pipe. The agreement with Professor Allen's curve is very close.

The boom calibration in still water is equivalent to calibration in streamline flow and gives a value of coefficient higher than

[5] District Engineer, Bureau of Agricultural Engineering, Milwaukee, Wis.

[6] "Cost of Pumping for Drainage in the Upper Mississippi Valley," by J. G. Sutton, U. S. Department of Agriculture Technical Bulletin No. 327, October, 1932. Also, "Design and Operation of Drainage Pumping Plants in the Upper Mississippi Valley," by J. G. Sutton, U. S. Department of Agriculture Technical Bulletin No. 390, November, 1933.

[7] Professor of Civil Engineering, University of Pennsylvania, Philadelphia, Pa.

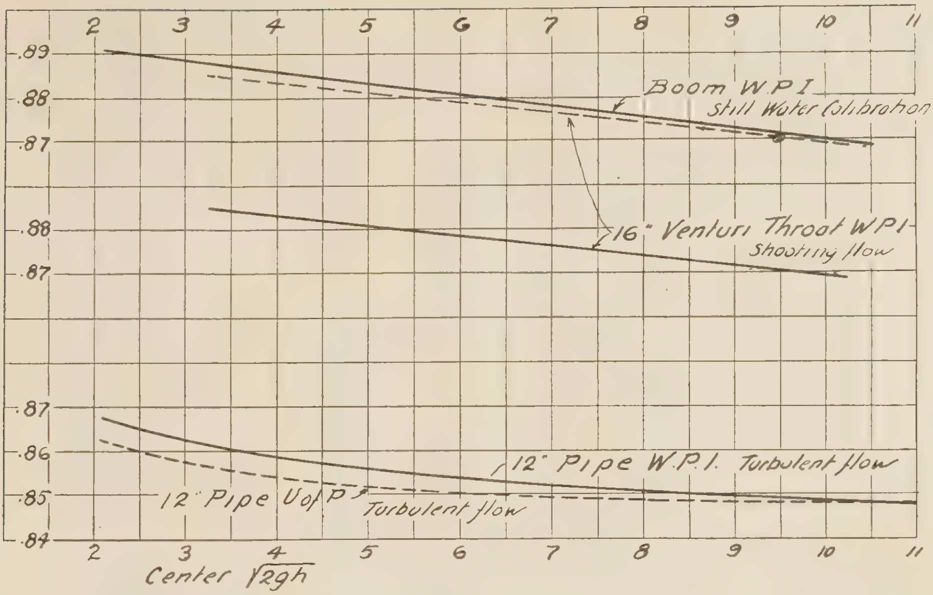


FIG. 3 CALIBRATION OF PITOMETER NO. 617 AT WORCESTER POLYTECHNIC INSTITUTE AND UNIVERSITY OF PENNSYLVANIA

the calibration in the 12-in. pipe. The writer believes this is entirely reasonable. When Professor Allen places the pitot tube in the 16-in. venturi-meter throat he places it in a region of shooting flow because the stream lines are parallel. Hence, he obtained the same coefficient as by means of the boom, but when the tube was calibrated in turbulent flow in the 12-in. pipe the coefficient was about two points lower. This is about what could be expected.

Some time ago experiments were conducted on a plain pitot tube with wall connections for various types of tip. This is shown in Fig. 4 of this discussion. The counterbored type gave a coefficient of about 0.98 and the calibration was fairly flat. The turn-point tube averaged about 0.985 and had a distinctly rising

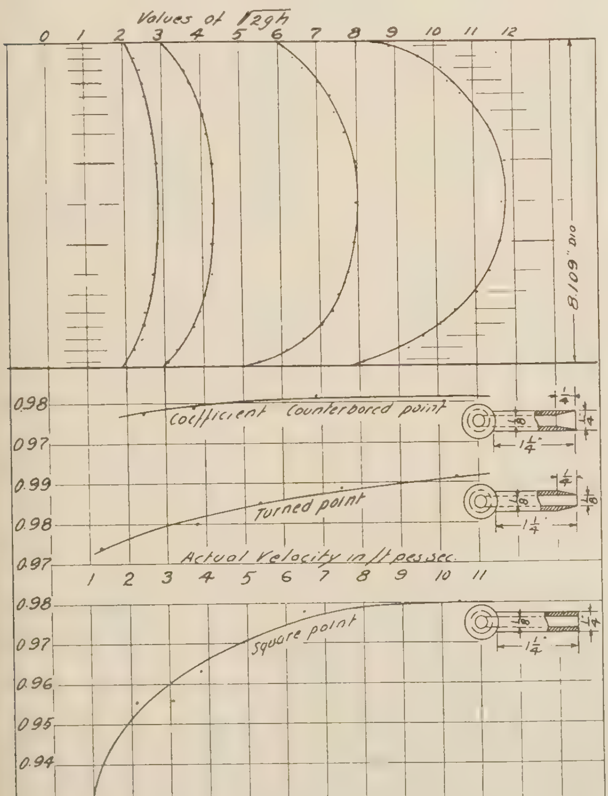


FIG. 4 CALIBRATION CURVES FOR COUNTERBORED-POINT, TURNED-POINT AND SQUARE-POINT PITOT TUBES

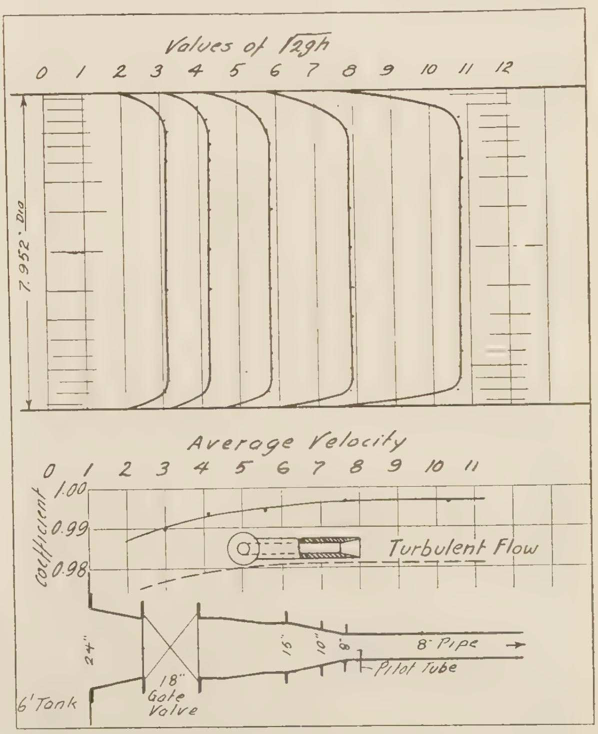


FIG. 5 CALIBRATION CURVE FOR COUNTERSUNK PITOT TUBE IN APPROXIMATELY SHOOTING FLOW

characteristic. The square-point tube gave a maximum coefficient of 0.98 and varied more than either a counterbored or a turn-point tube. The velocity traverses shown in Fig. 4 of this discussion for the counterbored point are typical of turbulent flow in an 8-in. pipe.

This tube was moved upstream 6 in. after a gradual decrease from 24 in. to 8 in., giving a condition quite similar to that obtained by Professor Allen in a 16-in. venturi throat. The resulting curves are shown in Fig. 5 of this discussion together with the pipe arrangement. It will be observed that the average value of the coefficient is 0.995 and it approaches 0.997 as a maximum. It will be reasonable to assume that such a tube will give a coefficient of unity on Professor Allen's boom. It will be observed that the coefficient rose from 0.98 in turbulent to 0.995 in shooting flow, this being an increase of 0.5 per cent, which is a fairly close check of the variation shown in the case of tube No. 617 in Mr. Cole's paper.

This variation in coefficients in different types of flow is probably due to the fact that the pitot tube in diagonal flow measures a head greater than that due to the cosine function. Hence, it will overrecord and give a coefficient of less than unity in turbulent flow. The writer could introduce a great deal of information to indicate that the coefficient of plain pitot tubes in turbulent flow is very close to unity, but believes that this is unnecessary.

(Discussion following was given jointly with the paper by W. M. White and W. S. Rheingans.[8])

W. B. Gregory.[9] The pitot tube has become in recent years an instrument of precision and reliability. It is made and used in many forms; knowledge regarding its peculiarities, limitations and adaptability is being accumulated through papers such as presented by Mr. Cole and Messrs. W. M. White and W. J. Rheingans.[9]

The writer developed an interest in the pitot tube when he was a student at Cornell University. A thesis on the testing of the hydroelectric power plant of the Ithaca Street Railway Company developed the necessity for some means of measuring the velocity of water in a penstock 5 ft in diameter and more than 100 ft long. A conference with Prof. I. P. Church resulted in the construction of the crude tube of Fig. 4 of the paper by E. S. Cole. It was calibrated by pouring red coloring matter into the intake and recording the time for the color to appear from a small tap about 95 ft down the pipe. In spite of the crudities involved a fairly satisfactory calibration was obtained. In fairness to Professor Church it should be said that the tube was designed by the writer.

The writer's next use of the pitot tube was in New Orleans in connection with the test of the Jourdan Avenue Drainage Pumping Station during the period between 1897 and 1900. Another pitot tube was built which gave correct results when W. M. White calibrated it later by drawing it through still water in the Jourdan Avenue Canal. Both the tubes previously mentioned by the writer had satisfactory impact tubes but failed to record the correct static pressures.

In 1901 W. M. White showed that it is relatively easy to construct the impact tube to give correct readings but that the static readings are often increased because of the turbulence of the fluid in the vicinity of the static openings.[10] This paper reported a masterly piece of research and suggested a form of tube with constant of unity. It consisted of separate pipes for impact and for static readings and was not suited for use in making traverses of pipes or conduit where pressure and velocity readings are desired at the same point. The writer's contribution to the pitot tube was the combining of the two tubes, by placing one within

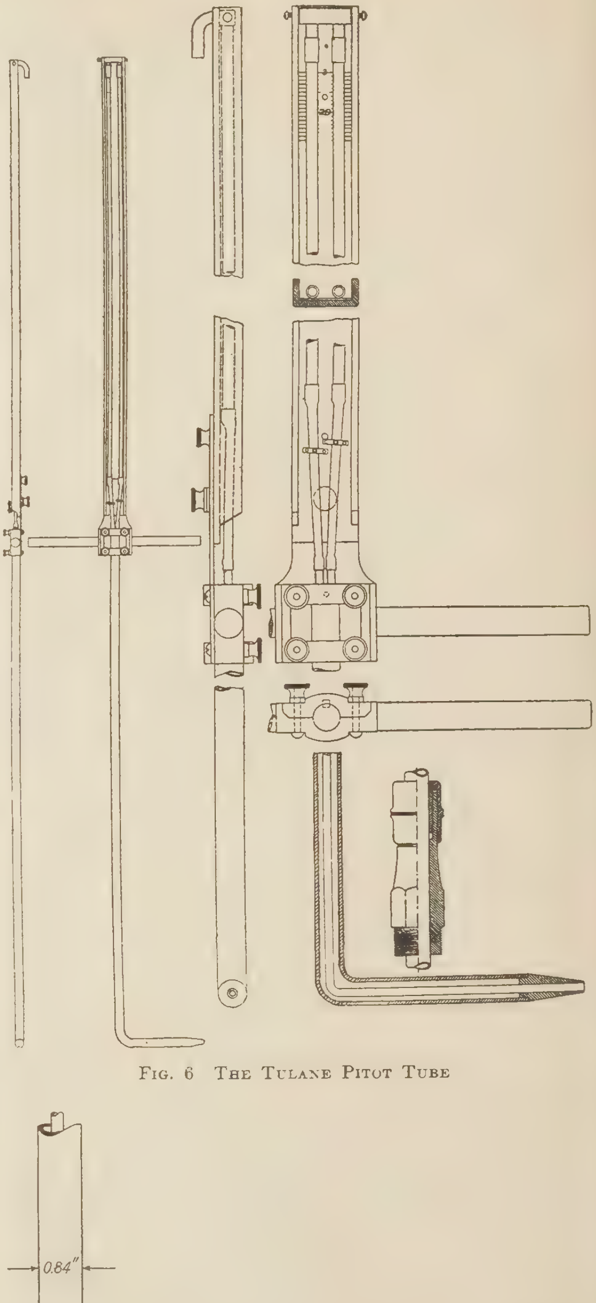

Fig. 6 The Tulane Pitot Tube

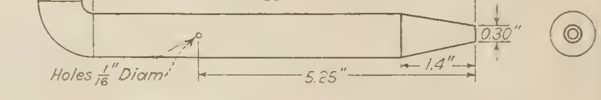


Fig. 7 Dimensioned Drawing of Tulane Pitot Tube

[8] "Photoflow Method of Water Measurement," by W. M. White and W. J. Rheingans, Trans. A.S.M.E., vol. 57, August, 1935, p. 273.

[9] Professor of Experimental Engineering and Hydraulics, Tulane University, New Orleans, La. Mem. A.S.M.E.

[10] "The Pitot Tube; Its Formula," by W. M. White, The Journal of the Association of Engineering Societies, vol. 27, August, 1901, p. 35.

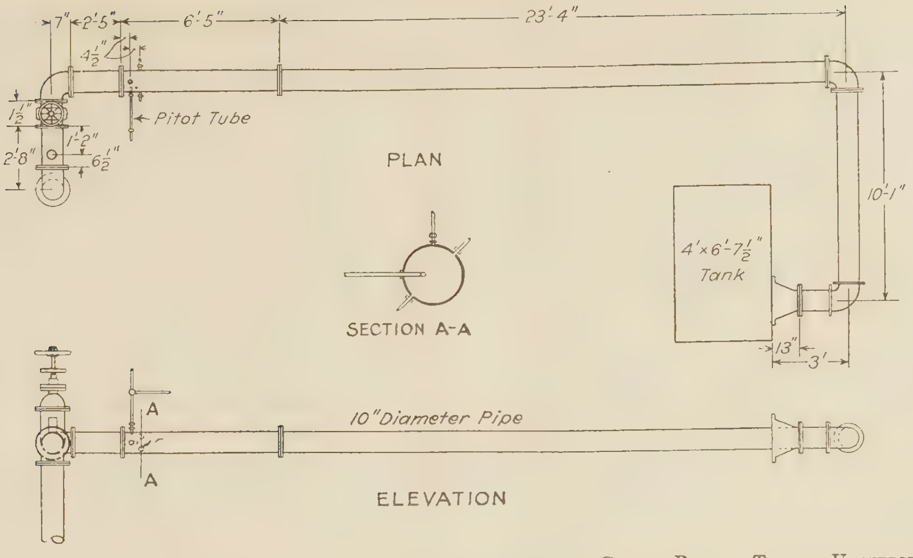


FIG. 8 ARRANGEMENT FOR MAKING PITOT-TUBE TRAVERSES OF A CLOSED PIPE AT TULANE UNIVERSITY

the other, utilizing the principles pointed out by White. The first tube, shown in Fig. 6 of this discussion, was made at Tulane University and is still in use. A dimensioned drawing of the Tulane pitot tube is shown in Fig. 7 of this discussion.

As noted previously, White calibrated the tubes by drawing them through quiescent water and obtained a constant of unity. Later, when the tube was used in pipes where the flow was turbulent, a constant of slightly less than unity was used by some experimenters.

The Gregory and Maltby pitot tube was not developed nor used at Ithaca, N. Y., as mentioned by Mr. Cole, but at West Memphis, Tenn., where the headquarters of the dredging fleet of the Mississippi River Commission was located. The tube was designed and built in 1903 by F. B. Maltby, superintendent of dredging; the writer assisted while it was being calibrated by means of floats.

About 1905 A. B. Wood of the Sewerage and Water Board of New Orleans built three tubes which have been used in hundreds of tests of hydraulic machinery. In some cases where the tube was used, traverses were made of pipes discharging into or from concrete basins where volumetric checks were made. The constant was found a repeated number of times to be practically unity. Although this work was done about thirty years ago, Mr. Wood and his assistants still use the pitot tube and believe its constant is near unity. The writer has used the pitot in hundreds of tests and has usually employed a constant of unity. What other method of water measurement can be used with a probable accuracy of 2 per cent which is at all comparable with the pitot tube in cost and ease of manipulation?

The simple form of the pitot tube with wall piezometers was used by Dr. E. W. Schoder and the writer at Cornell University in 1907 and 1908. Velocities obtained by means of the tube were compared to those from a carefully calibrated nozzle.[11] The following is quoted from the paper. "The results indicate an average error of about 1 per cent while the greatest error is about 3 per cent. As variations as wide as the above may be expected in work of this kind, even when conducted with the greatest care, the conclusion that the coefficient of the tube is unity is justified. Probably a greater number of traverses would have given an average still nearer to unity."

In an experience in measuring water extending over many years the writer has had many opportunities to compare results obtained by means of the pitot tube with other means of water measurement. He has used it in flumes having velocities of about 4 fps and has obtained results which check closely those from a current meter. This has been done many times.[12] In the test of the Connersville Pumps at the Neches Canal, Beaumont, Texas, 1906, where the two instruments were used alternately the average of 9 readings with the current meter gave a discharge of 152.99 cu ft per sec while the average displacement of the pump for corresponding readings was 152.90. The pitot tube for 12 readings gave average discharge of 152.79 cu ft per sec while the average displacement of the pump for these readings was 152.92. The greatest deviation of any single reading of slip was less than 2 per cent from the mean; some were negative and some positive and the average slip was zero. A repetition of this test in 1915 by the writer and Prof. W. Trinks, gave for a shorter test, a slip of 0.79 per cent and substantial agreements in main results.

In Louisiana and Texas with irrigation and drainage pumping plants to be tested the pitot tube has been the instrument that has made these tests possible at reasonable cost. Flumes are often found in irrigation plants and if the flume is sufficiently long and other conditions are favorable a current meter may be used. But in pumping plants for drainage it is seldom that conditions are found which are favorable to the use of any instrument but the pitot tube. Often it must be used in a suction pipe or pipes. After using the instrument in many cases where results could be compared and evaluated the conviction has grown that the tube used intelligently is an accurate instrument.

The question is, how accurate? The answer must be obtained from calibrations which can be checked by weighing or by volumetric measuring. This has been done for the pitometer in the hydraulic laboratories of Worcester Polytechnic Institute and at the University of Pennsylvania as described in Mr. Cole's paper. Only in the last two or three years have the facilities for accurate calibrating of the pitot tube been available in the Tulane Hy-

[11] "Some Pitot Tube Studies, the Distribution of Velocities and Pressures in Straight and Curved Portions of Six-Inch Water Pipe," by W. B. Gregory and E. W. Schoder, Trans. A.S.M.E., vol. 30, 1908, p. 351.

[12] "Test of a Rotary Pump," by W. B. Gregory, Trans. A.S.M.E., vol. 28, 1907, p. 745.

TABLE 1 PITOT-TUBE CONSTANTS OBTAINED AT TULANE HYDRAULIC LABORATORY

| Test no. | Date | Traverse | Static press from | Time for 6000 lb, sec | Velocities by Weight | Velocities by Pitot | Coef $c$ |
|---|---|---|---|---|---|---|---|
| 1 | 11-16-34 | H | W.P. | 27.87 | 6.187 | 6.311 | 0.9803 |
| 2 | 11-16-34 | H | W.P. | 27.95 | 6.171 | 6.321 | 0.9782 |
| 3 | 3-12-35 | H | Pitot | 27.85 | 6.190 | 6.380 | 0.9700 |
| 4 | 3-12-35 | H | Pitot | 27.85 | 6.195 | 6.344 | 0.9780 |
| 5 | 3-16-35 | H | Pitot | 27.90 | 6.175 | 6.373 | 0.9700 |
| | | | Average of horizontal traverses = | | | | 0.9753 |
| 6 | 3-16-35 | V | Pitot | 27.55 | 6.255 | 6.322 | 0.9890 |
| 7 | 3-19-35 | V | Pitot | 27.75 | 6.200 | 6.322 | 0.9810 |
| 8 | 3-19-35 | V | Pitot | 27.82 | 6.200 | 6.303 | 0.9840 |
| 9 | 3-19-35 | V | W.P. | 27.65 | 6.230 | 6.326 | 0.9850 |
| 10 | 3-19-35 | V | W.P. | 27.72 | 6.220 | 6.343 | 0.9800 |
| | | | Average of vertical traverses = | | | | 0.9838 |
| | | | Average of horizontal and vertical traverses = | | | | 0.9795 |

H = Horizontal.
W.P. = Wall piezometer.
V = Vertical.

TABLE 2 DETAILS OF TESTS 5 AND 6 OF TABLE 1

| Station | Test no. 5[a] $h_1$ | $h_2$ | $h$ | $v$ | Test no. 6[b] $h_1$ | $h_2$ | $h$ | $v$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.390 | 0.990 | 0.400 | 5.07 | 1.132 | 0.710 | 0.422 | 5.21 |
| 2 | 1.463 | 0.930 | 0.533 | 5.86 | 1.196 | 0.660 | 0.536 | 5.87 |
| 3 | 1.520 | 0.877 | 0.643 | 6.43 | 1.260 | 0.603 | 0.657 | 6.50 |
| 4 | 1.565 | 0.835 | 0.730 | 6.86 | 1.308 | 0.570 | 0.738 | 6.89 |
| 5 | 1.626 | 0.783 | 0.843 | 7.37 | 1.363 | 0.517 | 0.846 | 7.37 |
| *C* | 1.666 | 0.750 | 0.916 | 7.67 | 1.394 | 0.492 | 0.902 | 7.62 |
| 6 | 1.648 | 0.763 | 0.875 | 7.50 | 1.368 | 0.516 | 0.852 | 7.40 |
| 7 | 1.593 | 0.814 | 0.779 | 7.08 | 1.302 | 0.562 | 0.740 | 6.90 |
| 8 | 1.528 | 0.872 | 0.656 | 6.50 | 1.250 | 0.613 | 0.637 | 6.40 |
| 9 | 1.470 | 0.913 | 0.557 | 5.99 | 1.182 | 0.664 | 0.518 | 5.77 |
| 10 | 1.383 | 0.983 | 0.400 | 5.07 | 1.102 | 0.728 | 0.374 | 4.91 |
| | Average without $C$ = 6.373 | | | | Average without $C$ = 6.322 | | | |

[a] Horizontal traverse.
[b] Vertical traverse.

draulic Laboratory. The work done has not been in the nature of exhaustive research but may prove of interest and will be given as a contribution to this discussion.

The equipment, shown diagrammatically in Fig. 8 of this discussion consists of a 10-in. steel pipe, axis horizontal, on which a constant head may be maintained by pumping, causing a constant velocity of flow. Across this pipe traverses may be made in vertical or horizontal planes. Although the plane of traverse is about 34 diameters from an elbow which lies in a horizontal plane, there is but slight distortion of the velocity curve. The tube is 0.4 in. in diameter; it was first arranged with wall piezometers on opposite sides of the pipe in a plane passing through the axis and at 45 deg with the horizontal plane. Ten-point traverses made by student classes in hydraulics last year gave pitot-tube constants $c$ as follows: Average = 0.976, maximum = 0.984, and minimum = 0.967. There were 30 traverses in all, three of which were rejected because of apparent errors. The averages given are from the remaining 27 sets of readings.

A small model of the Tulane pitot tube was made by reducing all dimensions in proportion from 0.84 in. to 0.40 in. diameter of pipe. The small tube has static openings so that it was not necessary to use the wall piezometers although a comparison could be made between the wall static pressures and the static of the pitot tube. Five carefully made traverses gave an average value of $c$ of 0.9753 for horizontal traverses and 0.9838 for vertical traverses or an average for all the traverses of 0.9795. The details are given in Table 1 of this discussion. Table 2 of this discussion gives the details of traverses Nos. 5 and 6 which are shown graphically in Fig. 9$b$ of this discussion.

The difficulties involved in obtaining a correct static reading by means of a pitot tube has already been referred to. The difficulties involved in obtaining the same static reading on different sides of the same pipe, even when great care is used in

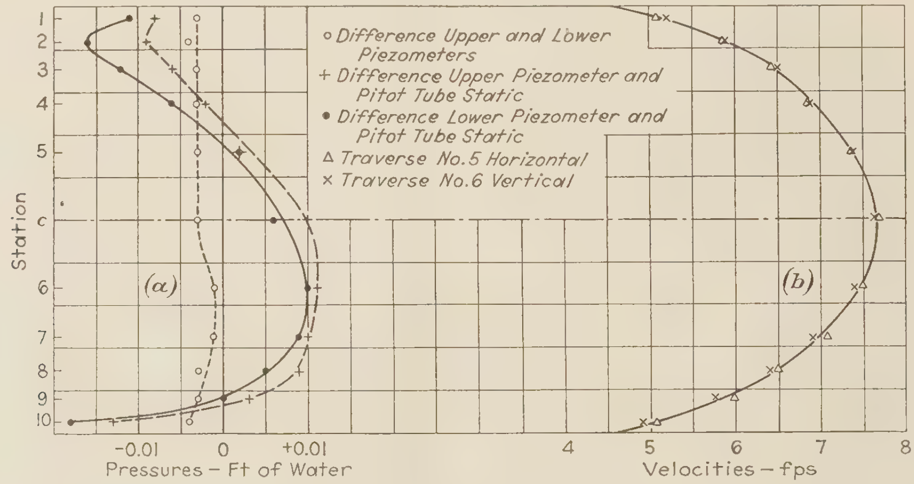


Fig. 9

TABLE 3 COMPARISON OF PITOT-TUBE AND PIEZOMETER READINGS[a]

| Station | Upper piezometer | Pitot tube | Difference | Lower piezometer | Pitot tube | Difference | Upper piezometer | Lower piezometer | Difference |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.320 | 1.312 | −0.008 | 1.455 | 1.444 | −0.011 | 1.380 | 1.377 | −0.003 |
| 2 | 1.320 | 1.311 | −0.009 | 1.458 | 1.442 | −0.016 | 1.380 | 1.376 | −0.004 |
| 3 | 1.318 | 1.312 | −0.006 | 1.456 | 1.444 | −0.012 | 1.379 | 1.376 | −0.003 |
| 4 | 1.317 | 1.315 | −0.002 | 1.454 | 1.448 | −0.006 | 1.379 | 1.376 | −0.003 |
| 5 | 1.315 | 1.317 | +0.002 | 1.450 | 1.452 | +0.002 | 1.379 | 1.376 | −0.003 |
| *C* | 1.310 | 1.320 | +0.010 | 1.447 | 1.453 | +0.006 | 1.378 | 1.375 | −0.003 |
| 6 | 1.310 | 1.321 | +0.011 | 1.446 | 1.456 | +0.010 | 1.377 | 1.376 | −0.001 |
| 7 | 1.310 | 1.320 | +0.010 | 1.446 | 1.455 | +0.009 | 1.377 | 1.376 | −0.001 |
| 8 | 1.310 | 1.319 | +0.009 | 1.447 | 1.452 | +0.005 | 1.378 | 1.375 | −0.003 |
| 9 | 1.312 | 1.315 | +0.003 | 1.450 | 1.450 | 0.000 | 1.378 | 1.375 | −0.003 |
| 10 | 1.320 | 1.307 | −0.013 | 1.458 | 1.440 | −0.018 | 1.378 | 1.374 | −0.004 |

[a] All readings given in feet.

the piezometer openings, has been shown in another paper.[13] A sample of piezometer studies is given in Table 3 of this discussion and graphically shown in Fig. 9*a*. In taking these readings the pitot tube was placed at the various stations in succession and the readings taken. The upper and lower wall piezometers show differences of pressure that are not great and are nearly constant as the pitot tube was moved across the pipe. The difference between the static pressure from the pitot tube and the two wall piezometers is considerably greater and varies in a peculiar way across the pipe.

Engineers are interested in the pitot tube as a scientific instrument and as a reliable and accurate device for obtaining the velocity of water. Future researches may clear up some of the vagaries of angular flow and of turbulence, and determine the best dimensions and shape of the tube and the proper location of static openings.

The evidence to date seems to indicate that a carefully made simple tube with wall piezometers and also the combined tube of the type of the Tulane pitot tube will have a constant of approximately 0.98 in turbulent flow and practically unity under the most favorable conditions of flow. Those of us who have used the larger coefficient have certainly been within 2 per cent of the truth and possibly closer. How can water be measured as accurately at a reasonable cost?

### Author's Closure

The author heartily agrees with R. J. Pigott that the "pitot tube has an easily determinable and reliable coefficient" and he further agrees that "it is as accurate as any of the other primary devices when properly handled," but he differs with him regarding certain details of theory and practice.

The symmetry of the velocity traverses does not of itself prove a lack of disturbance because in the 12-in. and also in the 40-in. steel pipes of the Alden Laboratory we measured a mean angularity of about 5 deg with occasional jumps to 10 deg and 15 deg, although the traverse curves are quite symmetrical as shown in Fig. 13 of the paper. The traverse curves for the 40-in. pipe and for several much larger pipes are not presented for lack of space. Lack of symmetry is, however, believed to indicate a disturbed flow but "symmetry" is hardly the criterion by which to judge of flow conditions, for example, certain traverses with depressed centers may be symmetrical with respect to pipe axis and yet indicate a disturbed flow.

Mr. Pigott states that pipe factor increases with Reynolds' number but the work of Stanton and Pannell[14] shows that it increases so slowly that in water measurements, as referred to in the paper, the pipe factor at all ordinary velocities in a given pipe line may be considered as practically a constant.

In regard to the effect of the supporting rod upon the instrument coefficient the work of Ower[15] would indicate that at the equivalent water velocities of about 5 fps the supporting rod may affect the coefficient of a pitot tube as far as 20 support diameters upstream. Hence, a theoretical analysis of rod-area correction becomes unsatisfactory and the results obtained by actual tests of area effect, as described in the author's paper, would appear to be more reliable.

It should be noted that the difference between the mean value and either the Alden Laboratory or University of Pennsylvania correction curves as shown in Fig. 18 is small when overall accuracy is considered.

[13] "Piezometer Investigation," C. M. Allen and L. J. Hooper, Trans. A.S.M.E., vol. 54, no. 9, 1932, paper HYD-54-1, pp. 1–16.

[14] "Similarity of Motion in Relation to Surface Friction of Fluids," by T. E. Stanton and V. R. Pannell, National Physical Laboratory, Collected Researches, vol. 11, 1914, p. 293.

[15] "Measurement of Air Flow," by E. Ower, Chapman & Hall, London, 1927.

The author disagrees with the assertion of Mr. Pigott that the coefficient depends upon the pipe factor. The author contends that the coefficient depends mainly upon the form of the pitot tube and its proper correction for rod area as described in the paper. The effect of turbulence upon a pitot tube of the combined type should be to change its coefficient in agreement with the cosine of the existing angularity. Two forms of tube are presented, one of which overreads to the extent shown in Fig. 27 and the other underreads the cosine of angular flows to the extent as shown in Fig. 31.

In this connection it is interesting to note that the heavy-duty pitot tube shown in Fig. 29 has been rated in the 40-in. steel pipe at the Alden Laboratory and also on the revolving boom. Its area correction was determined by building up its cross section in steps as described for type of tube shown in Fig. 6 of the paper. The area correction was found to be 1.05 times the per cent change in the pipe area due to the rod projection, and with this correction the 40-in. pipe coefficient becomes 0.953 which compares with the coefficient of 0.957 as obtained on the revolving boom in still water. Therefore it would seem to be significant that both the overreading and the underreading type of tube should have practically the same coefficient in pipes when corrected for rod area, as was obtained in still water.

In reply to F. H. Rogers, the author would call attention to the fact that the flow in the 12-in. pipe at the University of Pennsylvania was evidently disturbed, as shown by the character of the traverses in Fig. 21 of the paper, and yet the coefficients agreed closely with those found at the Alden Laboratory where the 12-in. pipe traverses were more satisfactory.

Mr. Rogers' assumption that the author's pitot tube shown in Fig. 6 of the paper is unsuited to large pipes or to small pipes with turbulence is well answered by the results recently obtained for the author at the Alden Laboratory in a 40-in. steel pipe. Flow was measured over a weir carefuly calibrated for this test by means of tank and scales. Two of the same pitot tubes were used as in the original tests in 12-in. pipes and the same method of obtaining the rod-area correction was employed as described in the author's paper for 12-in. pipe. These pitot tubes were rated as before in the 16-in. throat of the venturi meter with tank and scales giving a mean coefficient of 0.870. In the 40-in. pipe, a coefficient of 0.863 was obtained which becomes 0.869 when corrected for rod area, using the mean value given in Fig. 18 of the paper. In view of this and considering the many successful gagings made by the author and others in larger pipes,[16] it would seem that Mr. Rogers' assumption may be at fault.

Mr. Rogers also assumes that a mean angularity of 10 or 15 deg is commom in normal pipe lines and others have claimed angularities as great as 30 deg or more. Such claims seem to rest upon inference only. A coefficient is obtained in a pipe line and by means of laboratory tests it is then found that the simple pitot tube must be turned to an angle of 30 deg in order to produce that coefficient. This seems to be the only basis for these claims while from actual measurement of turbulence, as described by the author in his paper, no such angularity has been found in normal pipe lines.

As for the coefficients reported by Mr. Rogers and on which he bases his belief in high angularity, it is seen that they were obtained with large weirs as in the case of the 9-ft pipe at Shawinigan Falls which gave the simple pitot tube with wall-piezometers a coeficient of 0.9761 to 0.9785 from which the angularity of 15 deg was inferred. The author has no such faith in the accuracy of large weirs and in the absence of information on the method of their calibration he is unconvinced.

[16] "Research Institute for Hydraulic Engineering and Water Power," Trans. A.S.M.E., vol. 55, 1933, paper HYD-55-3, p. 33. See Walchensee tests.

In the discussions of Prof. W. B. Gregory and John G. Sutton there is evidence of much practical experience in water measurement with the pitot tube, and it is unfortunate that a higher degree of accuracy is not believed by them to have been attained. This is probably due to difficulties of the field testing of drainage pumps often working under negative heads and perhaps with unsatisfactory gaging points available.

The author gratefully acknowledges the assistance of Prof. C. M. Allen, L. J. Hooper, and Clyde Hubbard of the Alden Laboratory, Prof. W. S. Pardoe of the University of Pennsylvania, and E. Shaw Cole, in the preparation of the paper.

# Photoflow Method of Water Measurement[1]

F. H. Rogers.[2] The photoflow method of water measurement described in the paper is a very ingenious and apparently accurate method of determining the flow in closed conduits or penstocks. It is certainly an advance over the well-known method of pitot-tube traverses used in the tests of many hydraulic turbines in the past. The new method has the definite advantages of greater accuracy, shorter time, and lower cost than the former traverse method, and the consistent results obtained in the test made on the units in the Little Falls Pumping Station proved that the photoflow method can be used under unfavorable conditions where turbulent flow occurs.

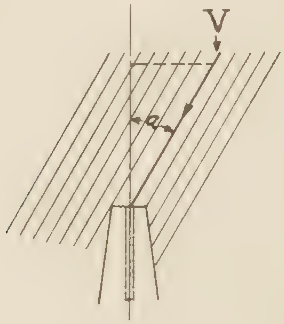


Fig. 1

The calibration tests of the various pitot tubes, shown in Fig. 1 of the paper were made by the writer in 1910 in the testing flume of the Rensselaer Polytechnic Institute at Troy, N. Y. As pointed out by the authors, for angular flow none of these tubes recorded the pressure corresponding to the resolved axial velocity, but all gave higher values, thus requiring a coefficient less than unity.

At the time the tests were made at Troy this characteristic of the pitot tube was studied to discover, if possible, a theoretical reason as to why the tube should read higher than the resolved velocity. It was felt, since the tube records pressure corresponding to the velocity head, that for angular flow it should read theoretically the resolved velocity head, rather than the head corresponding to resolved velocity.

Based on this theory the coefficient of a pitot tube may be calculated as follows: In Fig. 1 of this discussion let $V$ = absolute velocity of water; $a$ = angle of flow with axis of tube; $H$ = resolved velocity head; $V_1$ = velocity determined by tube, and $c$ = coefficient of tube. Since

$$H = (V^2/2g)\cos a$$

then

$$V_1 = \sqrt{[2g(V^2/2g)\cos a]} = V\sqrt{\cos a}$$

As the true resolved velocity is $V \cos a$, the coefficient of the tube will be

$$c = V\cos a/V\sqrt{\cos a} = \sqrt{\cos a}$$

For all angles of flow, except 0 deg, this coefficient will be less than unity.

It was found that tubes $B$, $E$, and $F$ in Fig. 1 of the paper, all of which had plane surfaces exposed to flow, gave coefficients which checked almost exactly the theoretical coefficient obtained from $\sqrt{(\cos a)}$ up to angles of 20 deg to 25 deg. Applying this same theory to the Little Falls tube, Fig. 2 of the paper is here reproduced as Fig. 2 of this discussion but to which has been

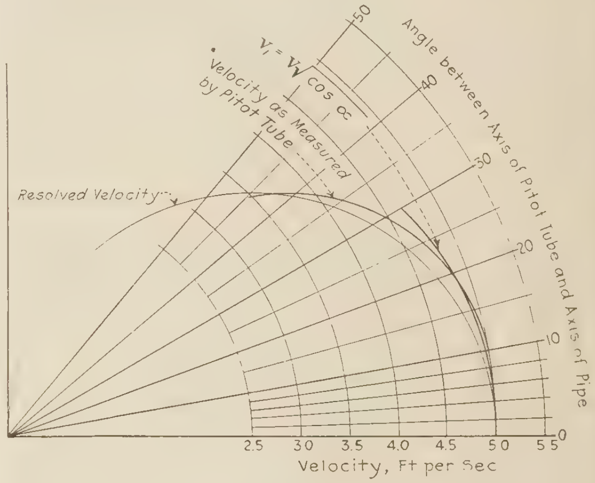


Fig. 2

added a third curve showing the velocity calculated from the theoretical formula

$$V_1 = V\sqrt{\cos a}$$

It is seen that the actual velocity, as measured by the pitot tube, checks the theoretical velocity $V_1$ very closely up to an angle of 20 deg, and thus again confirms the previously referred to theory.

With regard to the range in the values of the coefficient of the pitot tube, the average value of 0.976 suggested in the paper for normal flow condition appears to be supported by many independent calibrations. This coefficient would indicate, from Fig. 3 of the paper, an angular flow of about 20 deg from the Little Falls tube, or an angular flow of about 18 deg from tube $B$. Such oblique flow seems reasonable, even under normal-flow conditions in straight penstock sections.

The paper also fixes the lower limit of the coefficient of the tube tested at 0.970 for conditions of extremely disturbed and cross current flow. This value checks the minimum coefficient shown in Fig. 3 of the paper at angular flow of 30 deg and also the actual calibration of the tubes in tests of the turbines at Little Falls Pumping Station, based on volumetric measurement of the water. Due to the rather severe bends in the penstocks ahead of the measuring section, an average angular flow of 30 deg appears quite reasonable.

Under conditions of greater turbulence and for other designs of pitot tubes, lower coefficients have been found. For example, in the tests made at Rensselaer Polytechnic Institute at Troy,

[1] Published as paper HYD-57-7, by W. M. White and W. J. Rheingans, in the August, 1935, issue of the A.S.M.E. Transactions.

[2] Chief Engineer, I. P. Morris Division, Baldwin-Southwark Corporation, Philadelphia, Pa. Mem. A.S.M.E.

N. Y., as shown in Fig. 1 of the paper, tube $B$ shows a coefficient of about 0.95 at a 30-deg angle, and tube $E$ falls as low as 0.93 at an angle of 40 deg. In the tests made at Eddystone, Pa., described by S. L. Kerr,[3] a tube coefficient of 0.934 was obtained when artificial turbulence of considerable magnitude was introduced by baffles. The visual observation of the yarn streamers during this test showed a turbulent condition in which the angle of flow varied rapidly from 40 deg to 50 deg on either side of the axis. It is felt that such turbulent conditions actually do occur in large intake sections where racks, piers, supports, or other obstructions are located close to the measuring section, but it is unlikely that such flow conditions exist in closed penstocks even though bends may be present.

The authors point out that considerable error may occur in the pitot-tube traverse method, due to the velocity changes and the changing distribution of flow occurring at all sections within the conduit. This is undoubtedly true if single observations are taken for each setting of the tube. If, however, sufficient time is allowed to read the pitot tubes and piezometers for each setting of the tubes, at least five times, good average values are obtained and the total quantity flowing can be checked on repeat tests within very close limits.

For example, a test was made by this method in 1915 on a turbine built for the Grace Station of the Utah Power & Light Company. The turbine was rated at 16,500 hp under a 482-ft head. Traverses were made in an 81-in. diameter penstock, six pitot tubes and eight piezometer openings being used. At the maximum quantity of 419 cfs the velocity at the traverse sections was 11.7 fps. At six gate openings double traverses of all tubes were made for checking purposes. In these tests the variation of the quantity, as shown by a single traverse compared to the average of the two traverses, was only from 0.06 per cent to 0.55 per cent. The average variation for all six runs was 0.3 per cent.

In another test made in 1916 on a turbine in the Oneida Station of the Utah Power & Light Company, the quantity was determined by pitot-tube traverses. This unit was rated at 15,000 hp under a 140-ft head. Traverses were made in a 12-ft diameter penstock, six pitot tubes and eight piezometer openings being used. At the maximum quantity of 1126 cfs the velocity at the traverse section was 10 fps. Double traverses were made at four gate openings. The quantity shown by a single traverse as compared to the average of the two traverses varied from 0.14 per cent to 0.64 per cent. The average variation for all four runs was 0.3 per cent.

W. F. Durand.[4] This paper is most timely in calling attention to the hitherto insufficiently recognized fact of the time variation of the velocity of flow in a closed conduit at any one point, and of the consequent uncertainty surrounding any survey of the distribution of velocity over a cross section of the conduit by way of a time traverse. The variations in the velocity as reported in the paper give some idea of the character of the error made possible by such a procedure, especially in the case of turbulent and unsteady flow. These characteristics of the flow in conduits in general are now well recognized and have been made the subject of investigation in various laboratories, but have only recently begun to attract the attention in engineering circles which their importance merits.

The purpose of this comment on the paper by W. M. White and W. J. Rheingans is, however, rather to call attention to the basic theory on which the use of the pitot tube depends, and to relate its indications more definitely to this theory.

Conditions may be assumed as follows:

1 A so-called perfect fluid of indefinite extent, the ultimate particles of which move uniformly in straight-line parallel paths, i.e., steady laminar flow.

2 A tube of relatively small cross section, with the open end facing the flow and with the body of the tube lying in the direction of the flow, and the whole connected up after the well-known manner of the pitot tube. This brings the plane of the open end normal to the flow and disposes the body of the tube in such way as to give the minimum distortion in the lines of stream flow.

Under these conditions it can be shown by rigorous mathematical procedure that the lines of flow will dispose themselves symmetrically about the tube and that a central filament of this flow of indefinitely small section area will be brought to a full stop as it reaches the plane at the open end of the tube. This is the so-called stagnation point of the flow. Around this central filament the ultimate elements of the fluid will approach the plane of the opening, gradually slowing down as they approach nearer and coming almost but not quite to a full stop as they turn almost at a right angle and flow along the plane of the opening, and then become rapidly accelerated as they pass around the edge, turn again downstream and pursue their path along and near the body of the tube. The nearer the particle to this central filament, the more nearly will its velocity be brought to zero as it approaches and makes its turn; and the farther away, the less will be the curvature of its path as it approaches and passes around the tube end, and the less the consequent reduction in velocity.

Now, by Bernoulli's law, the dynamic head, transformed into pressure and measured by the tube as a part of its total reading, will be the integrated resultant of the elements of such pressure distributed over the face of the opening, and this will correspond to the integrated result of the losses in velocity suffered by these elements of the flow. Strictly speaking, only the central filament is reduced fully to rest, with the surrounding filaments in contact with the small area of the tube opening very nearly but not quite reaching this condition. In consequence, only over the indefinitely small element of area contacted by the central filament will the dynamic head in terms of pressure represent the full velocity of flow, while over the surrounding elements the pressure will be slightly less, the difference corresponding to the residual velocity left in these elements of flow as they move over the face of the opening.

Therefore it should be expected that the actual dynamic head indicated by the tube would be slightly less than that corresponding to the full velocity of flow, representing, as the former does, the average of a series of values only one of which has the full 100 per cent value.

However, a vast number of ratings of pitot tubes in actual fluids (air and water) under conditions substantially representing right-line flow, all agree in indicating a coefficient of 100 per cent, within the limits of accuracy of the measurements. The explanation of this is apparently to be found in two main considerations:

1 Even assuming a perfect fluid and ideal conditions, the residual velocity of the particles moving over the face of the opening is so small that the corresponding dynamic pressure head is nearly 100 per cent and for the average over this face the reduction of the velocity is so near to zero that only refined methods of measurement could be expected to indicate a coefficient other than 100 per cent. This may be the more readily perceived when it is remembered that a residual velocity of one part in ten will mean a residual energy and hence a residual-velocity head of one part in one hundred or again a residual velocity of one part in one hundred will mean a residual-velocity head of one part in ten

[3] "Research Investigation of Current-Meter Behavior in Flowing Water," by S. L. Kerr, Trans. A.S.M.E., vol. 57, August, 1935, paper HYD-57-9, p. 295.

[4] Professor Emeritus of Mechanical Engineering, Stanford University, Stanford University, Calif. Hon. Mem. A.S.M.E.

thousand. It is then quite understandable that with some small residual velocity of flow over the face of the tube, the residual-velocity head would be relatively much smaller and perhaps difficult to detect without refined methods of observation and measurement. In consequence, and in the absence of such refined measurements, the dynamic head would be measured as apparently 100 per cent.

2 We are, however, not dealing with a perfect or ideal fluid medium, but with actual fluids exhibiting both viscosity and compressibility. The influence of the latter in this connection may be neglected; but that of the former will operate to slow down the actual flow over the face of the tube and to reduce the sharp acceleration around the outer boundary of the tube opening. The general result will be, therefore, a still nearer approach to zero velocity for the particles flowing over the face of the tube and a still nearer approach to 100 per cent for the tube coefficient.

It is not surprising, therefore, that under the conditions of rating test with actual fluids, a coefficient of 100 per cent is indicated within the limits of accuracy available for such measurements.

If now the tube were turned so that the face is no longer normal to the flow, it is readily seen that the whole flow picture will be profoundly changed. In such case there is no ground for assuming that the decrease in the velocity of a filament of the fluid flowing over the face of the tube will have any simple relation to the component of field velocity normal to the face. In fact, the entire field of flow about the tube will now be dependent in some degree on the form and size of the body of the tube as well as on the angle of inclination. In any and all cases, however, it must be remembered that the pressure indication given by the tube is simply the integrated average result of the reductions in velocity experienced by the filaments in the field of flow which in their course pass to and over the face of the tube, and that the character of this flow rapidly becomes complex as the face of the tube is inclined from the normal.

Fundamental fluid mechanics thus give adequate ground for the general use of a coefficient of unity, while under ideal conditions and strictly speaking, it should be slightly less. It also indicates clearly why the tube cannot be expected to give similarly exact indications for the component of flow normal to the face when such face is oblique to the main direction of flow.

These various considerations again show clearly why, with the tube in normal use in turbulent flow with cross current and periodic changes in velocity both in magnitude and direction, we should expect the need of a rating coefficient somewhat as the authors of the paper have indicated. Perhaps the most surprising and gratifying consequences of these conditions are found in the indications of the relatively small influence due to turbulent and irregular conditions of flow, and in the resulting high and nearly constant value of the coefficient for apparently wide variations in these conditions.

Lewis F. Moody.[5] Prior to the introduction of the Gibson pressure-time method and the Allen salt-velocity method of measuring water, the pitot-tube method was one of the most approved means of measuring water in hydraulic turbine tests, and was widely used. The method of application of the pitot tube described in this paper represents a real advance in the technique of water measurement, and makes possible a rejuvenation of the earlier practice and a renewed utilization of this simple and useful instrument. Both turbine designers and users should welcome every practical means of securing performance data. Dr. White's pioneer work with the pitot tube and his convincing demonstration of its principle in 1901 entitles him to speak authoritatively on this subject; and the recent experiments reported by Dr. White and Mr. Rheingans are of much interest on both theoretical and practical grounds.

The older method of measuring conduit discharge by pitot tube, by traversing the measuring section with two tubes and taking readings at successive locations of the tubes, is still believed to be capable of giving reliable results, but only at the expense of a great amount of time and labor. A single reading of the tube at each point is not sufficient, but a series of readings must be taken covering a time interval greater than the cycle of variation of the velocities. The complete traverse, therefore, requires a long period of time, usually at least a half hour, even when a large company of observers and recorders may be used. In some of the older tests, eight or more men were used to make and to record the observations, which lasted for about 30 to 40 minutes for a single measurement under the best conditions. With the photoflow method, this time may be very greatly reduced, and the photographic recording precludes personal errors of observation.

This factor of time required for a single run, giving one point on the efficiency curve, is a serious one in the testing of turbines. The same difficulty as was encountered in the use of the older pitot-tube method also enters into measurements by current meter, and in even greater degree. It might be thought that no great harm would result from extending a measurement over a long time; but as pointed out by the authors the regime of flow in a conduit is continually changing, even if the total discharge is kept perfectly constant, which is rarely accomplished. In practice it is impossible to keep the head and power output of a turbine unit absolutely constant for a long period of time, and even if the water-measurement observations correctly correspond to the actual flow at each instant, the resulting turbine efficiency really represents an average value for at least a small range of discharges.

It will be evident, for example, for points at or near the peak of an efficiency curve, that the true maximum efficiency will not be obtained, but rather an average value which will necessarily be lower, although it is supposed to constitute a single point on the curve. The continually changing flow distribution of course introduces considerable possibilities of error, and any individual reading may not correspond at all correctly to the total discharge occurring at that instant. The unstable nature of the flow conditions at usual velocities is generally recognized, since usual magnitudes of velocity and size of conduit involve large Reynolds' numbers far beyond the critical values and far up in the zone of turbulent flow; so that the "mean velocities" which we are attempting to measure are only statistical averages of values subject to complex or random effects. Hydraulic experimenters are familiar with the difficulty of attempting to reestablish a given condition of flow if an experiment is interrupted and repeated. These difficulties still have to be struggled with in current-meter measurements, and it is encouraging to find that they have been minimized in the pitot-tube measurements by the use of photographic recording.

The paper points out the necessity for applying a coefficient of less than unity to the apparent velocities indicated by the tube to provide for the oblique and unsteady flows in the conduit. The good agreement of the angular tests shown in Fig. 3 of the paper with the experiments carried out in 1913 at Troy, in still water, by F. H. Rogers and the writer, is of much interest.[6]

In comparing the values of coefficients reported by Messrs. White and Rheingans with those found by S. L. Kerr,[3] one might

[5] Professor of Hydraulic Engineering, Princeton University, Princeton, N. J. Also Consulting Engineer, Baldwin-Southwark Corporation, Philadelphia, Pa. Mem. A.S.M.E.

[6] "Measurement of the Velocity of Flowing Water," by L. F. Moody. Proceedings, Engineers Society of Western Pennsylvania, May and June, 1914.

think at first glance, that some discrepancy exists. The writer is of the opinion that the differences may be readily accounted for. Dr. White and Mr. Rheingans are treating of the field of measurement in usual penstocks and conduits where ordinarily considerable straight lengths of conduit exist at the measuring section and where abnormal or artificial disturbances do not usually occur. Mr. Kerr's tests,[3] on the other hand, were purposely made to include artificial disturbances close to the measuring section created by wide bars of various forms introduced in the stream. Such obstructions are actually encountered sometimes in practice, as when a measuring section is immediately downstream from coarse racks and supporting structures. The abnormal turbulence of the complex and indeterminate flow conditions thus caused make such sections unsuited to precise measurements in the field, but nevertheless they sometimes exist.

Although the Little Falls measuring section, as pointed out in the paper, left much to be desired for a precise measurement, it may be noted that while considerable distortion of the flow was to be expected from the conduit bends near the section, the distortion could be measured and the angularity of the flow could be expected to be fairly permanent and not particularly unsteady. This condition is very different from a series of coarse bars or wide plates a short distance upstream from a section, as tested by Mr. Kerr,[3] where an abnormal and highly turbulent condition was created, the entire flow probably being broken up into small eddies.

In conclusion, it is hoped that the authors will have occasion to continue their work in the field, and in particular that opportunities may be found to compare the results by volumetric measurement with those given by their method when applied to favorable measuring sections.

Forrest Nagler.[7] The writer has long thought that any of the point-velocity methods of measuring water must be premised on a rigidly supported device that is symmetrical about an axis in line with the flow. This is in contrast to a device like the cup type of current meter that may overregister, or underregister when subjected to horizontal or vertical angularities. The symmetrical types of meters are confined to the axial-flow or screw types, with which alone some attempts may be made to register the desired cosine function as shown in Fig. 2 of the paper. The pitot type used by the authors possesses this inherently necessary qualification of symmetry about a mean flow line. Fig. 2 of the paper indicates that it approaches the desired cosine relationship more closely than any other device the writer has had contact with.

Naturally considerable attention must be given to the basic coefficient of the pitot tube and it is of interest that the authors have referred to what was, at one time, a rather intensive three-cornered argument between authorities as to the basic formula. If the writer remembers correctly, the late Gardner S. Williams held up one corner of this argument with Mr. Kent and Dr. White for several years, but conceded the 2 under the radical.

The authors' description of the flow of water as it "moves spirally, intermingles and rolls from the center of pipe to the wall and back to center, continuously, but without loss of position in the march of flow," was once very aptly pictured by Herschel as being similar to the contents of a feather bed blowing down an alley. Repetition of this description can hardly be too frequent to help dispel the incorrect impression of flow lines given by textbook sketches.

Referring to the author's description of the layout of the tube $B$ in a 12-in. pipe, the thought arises as to how much effect on the actual velocity in front of the opening was introduced by the changing projected area of the tube itself, as it was turned through varying angles. The increase in cross section could hardly have helped generally reducing the velocity in the center of the pipe, and whether the tip reached outside of that reduced area may be open to question. In any event the recorded cosine performance must be the result of more than the effect of the impinging angle itself.

Referring to the authors' Figs. 1, 2 and 3, it will be noted that tube $C$ of Fig. 1, and the tube on Fig. 3 do not differ very much. However, the former seems to require a minimum coefficient of about 0.92 at a 30-deg angle, whereas the latter requires a coefficient of about 0.97. The reason for this wide discrepancy is not quite evident. Furthermore, the curve on Fig. 3 indicates that the coefficient should never be below about 0.97 for a fixed angularity of 30 deg. Such fixed angularity is decidedly unusual in a parallel conduit, and is not in keeping with the "feather-bed" type of flow. With that type of flow, the angle varies continually from a certain maximum, such as 30 deg, through zero, and to a maximum in the other direction.

With such a condition, the average coefficient would naturally not be the extreme one, but rather would be the average between that extreme and unity. On the assumption that the coefficient curve may be approximated by a radial section through a paraboloid of revolution, the mean ordinate will be one half of the extreme one. From this relationship, it is difficult to see how the coefficient could ever be less than 0.985 for any degree of angularity with the tube shown in Fig. 3 of the paper.

Is it possible that there is an additional inertia effect, similar to that which exists with a current meter, due to its flywheel effect, which actually distorts the relationship shown in Fig. 3 of the paper, making the coefficient lower, much as shown in Fig. 1 of the paper?

To emphasize this point, it is difficult to see how a tube which, under the most extreme and fixed angularity overregisters enough to require a 0.97 coefficient, would require a coefficient anywhere near as low as 0.97, if the flow varied from zero up to any given angle, such as 30 deg, because the average under the curve up to that point certainly is much greater than 0.97.

With reference to the simultaneous photographing of the pitot-tube readings, it seems that the biggest advantage would arise because an actual picture is preserved of the source observations, in contrast to written figures which may contain errors of observation or recording not later checkable. A simultaneous recording of events may correctly summarize the conditions across the section at that instant, but only successive repetitions at intervals out of tune with possible pulsations can give a correct indication of the actual average flow. It is noted that the authors actually apply this method, as indicated in their Table 3. In this table, the instantaneous feature involves indications varying by nearly 2 per cent.

The same result is accomplished with the usual traversing-point method. This is true whether the point be rigidly fixed for each observation, or whether it be moved continuously, as was quite popular with Michigan engineers about twenty years ago. The velocity variations which the authors obtain by an instantaneous photograph are those which exist across the measuring section. Those which they obtain by taking repeated shots, are apparently those which may be described as variable velocity of the "slug of salt." The only danger in the latter, seems to be that of synchronizing the shots with the pulsations, which might introduce that type of systematic error which is infinitely worse than all accidental errors.

Probably one of the most vital defects in any point method lies in the effect of the insertion of a measuring device on the flow in a cross section All such point-method determinations basically tend to underregister because the flow directly in front of any

[7] Chief Engineer, Canadian Allis-Chalmers, Ltd., Toronto, Canada. Life Mem. A.S.M.E.

such indicating devices is automatically slower, by reason of the presence of that device, than it would be if it were not there. In other words, when a current meter or pitot tube is inserted in a cross section, the flow goes elsewhere. All writers on current meters and similar devices religiously avoid this basic consideration. The writer is not free from blame in this respect. An extreme view of this feature may be had by assuming an open channel, perhaps 10 ft deep and 20 ft wide. The hydraulic radius is proportional to 5, that is, the area divided by the wetted perimeter. The hydraulic radius of each half is 5, that is, 100 divided by 20. If we now insert a rod or a cable in the middle of one side, the hydraulic radius, if the current meter is at the bottom, is immediately cut in half, that is, reduced to $2^1/_2$. Moving water, especially when at slow velocity, responds very quickly to extremely minor influences, and for a condition like this, the side where the current meter is not in use, naturally picks up more flow, which is not recorded by the instrument. This extreme relation applies to all of the traversing type of supports, and to a limited extent, to all fixed types of supports. The tests made with the former can readily show 5 or 10 per cent underregistering of quantity. Groat[8] gives some very significant instances of error with a very usual arrangement of current meters. The pitot tube has the advantage that it presents less bulk or projected area to retard the flow where it makes its record, but like the cup type of current meter it overregisters the cosine function sufficiently to partly compensate for the inherent defect.

It is probably only the decided overregistering characteristics of the cup type of current meter, and of any type of current meter swinging free, which has permitted an accidental error compensation sufficient to permit tests to be accepted. When tests show efficiency well over 100 per cent, even the most rigid advocate of current meters will hesitate to back up their indication, such instances are on record. Unfortunately it is only those percentages above 100 per cent which are thrown out. If the flow to the turbine of 90 per cent actual efficiency is underregistered 10 per cent, so that the efficiency is indicated as 100, naturally the results are thrown out, but if the meter happens to overregister 10 per cent, so that the results are indicated at 80 per cent they are accepted without question, and the manufacturer has a real job on his hands.

It is because of this feature that the free-swinging meter, or any free-swinging device which must show those components indicated by the outer circle through 5 fps in Fig. 2 of the paper, are not to be considered in any kind of disturbed flow. It will be noted that the 100 per cent circle in Fig. 2 of the paper lies well outside of the pitot-tube measurement at all angularities above 10 per cent. The authors are to be congratulated on having based their method on a device which comes as close to the desired cosine indication as disclosed by their Fig. 2.

In addition, the use of a device which permits of the easy installation of a large number of points is conducive to reducing errors arising from distortion of flow caused by the insertion of a device of any kind. It seems, however, that the sectors of Fig. 6 of the paper are rather large, and that the line of pitot tubes with their support, would automatically locate them in an abnormally low-velocity region. This would require a decided increase in the coefficient which might place it well above unity. This consideration, and that arrived at from inspection of the authors' Fig. 3, wherein the minimum coefficient of 0.97 ought to be increased to something over 0.98 to allow for wobbly flow, seem to the writer to call for a coefficient decidedly in excess of 0.97. That the volumetric tests made by the authors check a coefficient of 0.973 seems merely to indicate that some other effect entered.

It would be of great interest to see a curve similar to the authors' Fig. 3, based on using the same pitot tube in a still-water rating tank and also in a smooth large-area stream of flowing water. To the fixed-angularity readings there should be added a set of "wobbly" readings, wherein the tube point is continually and rhythmically moved through various angles, up to successively greater ranges on both sides of neutral. Such a test would come close to defining the basic effect of disturbed flow in so far as it may be represented by varying angularity.

L. J. Hooper.[9] There are several points brought up in the paper by Dr. White and Mr. Rheingans on which more information would be desirable.

The most important question is the coefficient of the pitot tubes as used in this test. It is stated that the coefficient was found to be 0.973 in one case and 0.970 in the other and that the reason for this low coefficient is the turbulent or angular flow of the water in the test section. It is realized that the Little Falls Pumping Plant presented most unfavorable testing conditions with respect to turbulent and angular flow and that the low coefficient of about 0.97 may be due to this fact alone. However, the supporting evidence of this test leaves considerable doubt as to what range might be expected for the coefficient for future tests.

There has been considerable work done on pitot tubes by a number of investigators. They have been unanimous in their opinion that an impact point centrally located in a surface of revolution perfectly converts velocity into velocity head. In other words, the coefficient of such an impact tube is unity. Further, Dr. White's impact tube when rated by itself in smooth flowing water has a coefficient of unity.

Several years ago at the Alden Hydraulic Laboratory pitot tubes were rated in a 36 × 16-in. venturi throat and in a 12-in. line. The pipe factor in the first case was 0.956 and the flow conditions undoubtedly smooth. In the second case the pipe factor was 0.785 and the water flow was turbulent due to two elbows in planes at right angles to each other, being located 28 ft upstream. The coefficients of the tubes checked perfectly.

During the tests on the 12-in. line a sensitive angularity indicator was made and used. The maximum angle read was 3 deg and in general few readings were obtained in excess of 1 deg. It would seem from the description of the photoflow method that the magnitude of the angular flow was arrived at inferentially and was not measured directly. In other words, there may have been other causes for the apparent depression of the pitot coefficient from unity to about 0.97.

In the first place it can be shown both theoretically and experimentally that an obstruction in a water passage influences the direction and the magnitude of the velocities upstream from the obstruction. For instance, a 1-in. diameter pipe can have a 1 per cent effect upon the velocity at a distance of 5 in. upstream parallel to the axis of the pipe. Inasmuch as the pressure piezometers were only about 2 in. upstream from the frame, it is extremely likely that the form, size, and location of the grid supports had an influence on the apparent coefficient of 0.97.

In the next place the volumetric check of the coefficient is only as accurate as the determination of the volume and this in turn depends upon the calibration of a venturi meter. It would be of interest to know when and how this meter was calibrated and what further checks were available to insure that the meter was operating in the same fashion as it was when it was calibrated.

It would seem that a converging section such as the penstock contraction at the entrance to a scroll case would require special treatment in the location of the impact tips. The velocity traverse in this case would be flat over the central portion of the pipe with a sharp shoulder relatively close to the pipe wall. In a 16-in.

[8] "Chemihydrometry," by B. F. Groat, Trans. A.S.C.E., vol. 80, 1916, paper 1366, p. 951.

[9] Worcester Polytechnic Institute, Worcester, Mass. Jun. A.S.M.E.

venturi throat this shoulder is only $1^1/_4$ in. out from the wall. In such a case several velocity determinations must be taken between the shoulder and the wall of the pipe. On an equal-area basis a large number of impact orifices would then be necessary. In any case, near the wall of the pipe the orifices would be so close together that there is a strong likelihood of the tips interfering with each other hydraulically.

At one point in the text it is stated that "Thus accurate determinations of the average velocity is nearly impossible with past methods." The statement is very sweeping. Several pipe-factor determinations are recorded where there were ten or more points on each curve. Usually one point can be found which is about 1 per cent from the curve, but the remainder of the points lie well within 0.5 per cent of the curve. A water wheel on hand control regulated the flow of the water and the test conditions were similar to a commerical test. The discharge in all tests was measured by a 10-ft weir and a 36 × 16-in. venturi meter, both metering systems being calibrated by a weighing tank. However, the fact remains that an error larger than 0.5 per cent in determining the mean velocity was exceptional rather than the converse being true as stated in the paper.

E. S. Cole.[10] This paper has special interest since it questions the accuracy of the well-known pitot-traverse or pitometer method of flow measurement which has been extensively used in city water mains and water-power penstocks.

Many thousands of pitometer traverses have been made since 1896 when the method was developed, and it is safe to assume that very few of these tests would have been undertaken had it been necessary to cut the pipes, interrupt the flow or install the obstructing interior fixtures with the many pitot and piezometer connections as described in this paper.

The combined pitot tube or pitometer is quite well known. It carries both dynamic and static openings in the same tip, so formed as to read the cosine of angular flows to 6 deg of angularity. Greater angularity than this seems to be unknown in normal pipe lines such as are commonly found in power plants or city mains.

The pitot-traverse method may not be well suited to certain abnormal pipe locations but its velocity readings always indicate the suitability of a given location so that misleading results are avoided. Pitometer coefficients have been obtained with great care at Professor Allen's hydraulic laboratory at Worcester, Mass.

The extreme simplicity of the pitot-traverse method and the rapidity with which tests are made with it has always been its distinguishing feature.

A velocity traverse is usually made on two diameters at right angles. Pitometers are inserted through valves suitably spaced around the pipe section, and these valves may be installed without removing the water from the pipe line or interrupting the service. Readings of velocity head are recorded at the mid-width of a number of equal-area rings, usually ten in a large pipe, simultaneously on opposite sides of each ring. They are always recorded during a complete cycle of velocity variations with perhaps ten readings at each point, the mean of the square roots of these readings being plotted as one point on the corresponding velocity traverse. Thus four values of mean velocity are obtained for each ring spaced 90 deg apart, from which the ring discharge is computed. Certain refinements in this procedure have been suggested but are usually unnecessary.

The remarkable agreement of repeated velocity traverses and computations is evidence enough of their accuracy and dependability. Seldom do check traverses differ by as much as 0.5 per cent in normal pipe locations at uniform flow. Often this agreement is within 0.25 per cent or less under favorable conditions and this well-known fact should entitle the pitometer method to the highest respect.

The time required for making a traverse has been misrepresented in the paper, for with four pitometers at 90 deg it is possible to make a ten-ring velocity traverse in 20 minutes. The installation itself may be made very quickly, as the valves and shelter boxes are set in advance. The cost and inconvenience of an installation should always be considered along with the accuracy expected in comparing various test methods and when this is done the pitometer method compares favorably with any other.

Ring integration based on a velocity traverse not only gives flow but also fixes the ratio of mean to center velocity which is called the "pipe factor" since it reflects the roughness of pipe wall and the general flow characteristics of the actual pipe location. Having this pipe factor it is only necessary to read the center velocity to have at once a very accurate determination of flow at the moment. For example, with pipe factors fixed by velocity traverses made at five or six gate openings, it is possible to make any number of short tests at intermediate loads or to record the flow continuously if required.

In view of the many successful pitot-traverse tests, the authors' statement as to the inaccuracy of this method seems unwarranted.

To give but one example: At Walchensee in 1929 at half-load and at three-quarters load, the pitometer results were well within 0.25 per cent of current-meter and salt-velocity values in a steel pipe of about 7-ft diameter.

The authors claim that the photoflow method, with a coefficient of 0.976 in circular conduits "should have an accuracy of 0.5 per cent because of the narrow range limit of the coefficient for various conditions of flow," will bear more supporting evidence than has yet been presented. If, as is well known, a simple pitot tube has a coefficient of unity in straight flow, how is it that 0.98 is the largest angularity coefficient possible? For under favorable flow conditions, especially in converging sections, this coefficient should approach unity. It is to be noted that the angularity tests were made at one velocity only. The low coefficient obtained by the authors may have been due to (1) grid interference affecting the pitot readings, (2) effect of the closely spaced pitot tubes upon each other, (3) the small number of rings employed, or (4) an error in the calibration of the venturi meter which was used in volumetric tests. The claim that a coefficient of 0.976 is within 0.5 per cent of the correct value, therefore, seems to be unproved.

The statement regarding the "many high-frequency fluctuations in the water columns which tended to cancel each other" is interesting for with these water columns and their erratic jumping under air pressure, it seems unlikely that the camera should always record readings which are exactly related to one another. Any variation in the length or frictional resistance of the various connecting tubes must necessarily cause a lack of synchronism in the cycle phases, but this source of error seems not to have been considered by the authors.

The claim that the photoflow method at Little Falls gave the true flow within 0.25 per cent or less, therefore, seems rather too optimistic in view of the extremely unfavorable flow conditions and the nature of the volumetric test methods employed.

W. S. Pardoe.[11] The authors are to be congratulated for developing a method which makes it possible to use pitot tubes where, as in the case at the Little Falls Plant, the conditions are such at the metering section that vortex or diagonal flow is almost assured.

Numerous tests of plain pitot tubes in the hydraulic laboratory

[10] President, The Pitometer Company, Engineers, New York, N. Y. Mem. A.S.M.E.

[11] Professor of Civil Engineering, University of Pennsylvania. Philadelphia, Pa.

TABLE 1 TEST OF A PLAIN PITOT TUBE IN A 4-IN. BRASS PIPE

| | First reading | | Second reading | |
|---|---|---|---|---|
| Location | Gage reading | $\sqrt{(2gh)}$ | Gage reading | $\sqrt{(2gh)}$ |
| −8 | 0.510 | 2.84 | 0.605 | 3.09 |
| +8 | 0.515 | 2.85 | 0.665 | 3.24 |
| +7 | 0.610 | 3.10 | 0.765 | 3.47 |
| −7 | 0.650 | 3.20 | 0.850 | 3.66 |
| −6 | 0.690 | 3.30 | 0.940 | 3.85 |
| +6 | 0.695 | 3.31 | 0.935 | 3.84 |
| +5 | 0.715 | 3.36 | 0.945 | 3.86 |
| −5 | 0.765 | 3.47 | 1.06 | 4.09 |
| −4 | 0.865 | 3.69 | 1.15 | 4.26 |
| +4 | 0.830 | 3.62 | 1.09 | 4.15 |
| +3 | 0.910 | 3.79 | 1.185 | 4.32 |
| −3 | 0.920 | 3.81 | 1.25 | 4.44 |
| −2 | 0.990 | 3.95 | 1.36 | 4.63 |
| +2 | 0.980 | 3.93 | 1.34 | 4.60 |
| +1 | 1.030 | 4.03 | 1.42 | 4.73 |
| −1 | 1.050 | 4.07 | 1.43 | 4.74 |
| | | Total = 56.32 | | Total = 64.97 |
| | | Avg = 3.517 | | Avg = 4.062 |

First reading: Weight of water = 6005 lb; time = 5 min 14.1 sec; volume = 0.3068 cfs; velocity = 3.515 fps. Therefore $C$ = 3.515/3.517 = 0.999. Second reading: Weight of water = 7007 lb; time = 5 min 16.5 sec; volume = 0.3553 cfs; velocity = 4.07 fps. Therefore $C$ = 4.07/4.062 = 1.0015.

Specific gravity of gage liquid = 0.755.

Two readings taken at the mid-width of 8 equal-area rings.

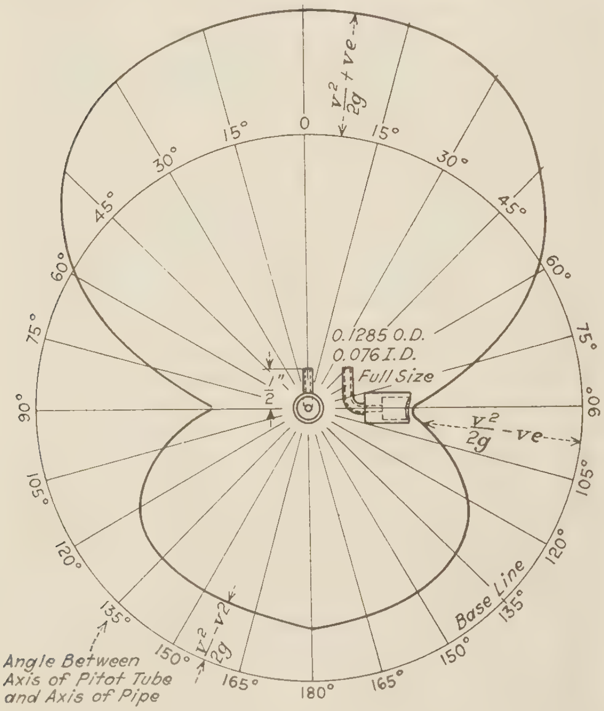


Fig. 3 Revolution of a Plain Pitot Tube in a 7-In. Pipe

of the Civil Engineering Department of the University of Pennsylvania have convinced the writer that the coefficient of a pitot tube with wall-piezometer connections is unity for turbulent nonvortex flow, that is, where the Reynolds number is well above 10,000. Table 1 of this discussion contains the results of recent tests which gave coefficients of 0.999 and 1.0015. A large number of other tests gave an average coefficient of 1.0012.

When the authors rotated the Little Falls tube at the center of a 12-in. pipe on the discharge end of a centrifugal pump, they could not have chosen in the writer's opinion a worse place for the location. Straightening vanes may have some beneficial effect. But aside from this fact, when the point of the Little Falls tube is rotated it is at least 2 in. away from the center line, and is at a point where the velocity is not equal to the central velocity and therefore should show a coefficient less than unity. In Fig. 3 of this discussion the writer presents a curve showing the effect of revolving a plain pitot tube in a 7-in. pipe. At 15 deg a coefficient of 0.999 was obtained while at 30 deg the coefficient was 0.986. These values were obtained in the 7-in. pipe with the tube shown in Fig. 3 of this discussion. This tube is $^1/_2$ in. long from the center of rotation.

The writer therefore is of the opinion that the authors must use a coefficient of unity and estimate the value of their $C$ from the surrounding conditions at the gaging section when flow is diagonal or vortex.

The writer does not agree that angular flow is "encountered in all conduits." Angular or vortex flow soon dies out in a straight line of pipe. Turbulence exists at all times, but the angle made by any particle is so small that its cosine is very near to unity. The writer cannot believe that the authors would like to use a coefficient of 0.976 in an acceptance test of one of their pumps.

J. F. Roberts.[12] The writer does not agree that any system of water measurement which measures the flow only to certain points is entirely accurate. The authors have taken the equivalent of three traverses of the pipe, one vertical and the other two at 60 deg from the vertical in both directions. An average of the vertical traverse readings taken from Table 1 of the paper is 5 per cent less than the value the authors have obtained for their answer. The traverse of points 5 to 10, inclusive, is 5 per cent too high, while the other diagonal points, 18 to 23, inclusive, are very nearly the mean of the other two and within 0.5 per cent of the answer they have obtained. It is questionable whether or not the authors have covered the area sufficiently with only three traverses but it is hoped that a sufficient number of points have been taken to give a true average. The same argument applies to current metering, and to the salt-velocity method when bowed electrodes are used to span the pipe.

In the writer's opinion, the best true average is obtained with the chemical or salt-solution method, provided the solution is given sufficient time to be uniformly mixed with the water. An infinite number of readings might be obtained with the salt-velocity method if two diaphragms of fine screening for electrodes were used, but in this method difficulties are encountered near the edge of the pipe in steel penstocks.

In making a test on a hydroelectric plant the question of time is often of prime importance. The authors mention that the photoflow method allows the test to be run in a minimum of time. However, in many cases, the time of testing is unimportant, but the "time of shutdown" to get ready for the test is very important. This time would be considerable for the photoflow method, whereas in moderate-head plants penstock can frequently be drilled for conventional pitot-tube and piezometer inlets without a shutdown.

Another point mentioned by the authors is that one man can conduct a complete test with the photoflow apparatus. This might be feasible, but certainly not desirable. The writer believes Mr. Groat[8] has expressed the situation very well when he said "An efficiency test cannot be efficiently conducted to obtain the true efficiency," meaning that plenty of help and a considerable number of gage readers and meter readers is desirable.

The authors state that none of the connections were throttled. This can only be true when the size of water passage is uniform from piezometer opening to gage glass. With a $^1/_{16}$-in. hole in the pitot tube, and glass tubing of $^1/_4$-in. to $^3/_8$-in. internal diameter, the throttling effect is considerable. What the authors have really obtained is an integrated mean of the rapid fluctuation or changes of velocity and pressure, and not an instantaneous reading of the true pressure at all of the tubes. However, the writer

[12] Hydraulic Engineer, Power Corporation of Canada, Ltd., Montreal, P. Q., Canada.

does not doubt but that by averaging six such readings a result very close to the correct one is obtained.

The authors are to be congratulated on the entire absence of integral signs and complicated equations in this paper. Surely in a paper dealing with $\sqrt{(2gh)}$ and integrated flow there is just as much opportunity for introducing long equations as in a paper dealing with surge tanks and pressure surges, but the authors have carefully avoided them. The writer feels that papers such as this are of far greater benefit if kept in the ordinary language of the commercial engineer.

J. D. Scoville.[13] In the last analysis is it not essential that the method described by the authors be applied only in straight

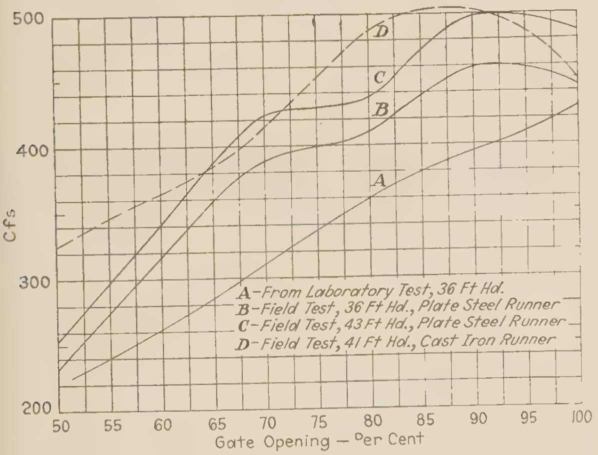


Fig. 4 Results of Multiple-Pitot-Tube Tests

penstocks where the flow is undisturbed and undistorted by elbows and obstructions? For accuracy, the method depends on the correctness of the pressure as well as the pitot-tube readings.

The authors refer to a paper on piezometers[14] and state that angular flow in a pipe may produce considerable error in the pressure observations. Are the authors justified in applying the method in a location such as Little Falls which would not be considered as suitable for a pitot-tube or pitometer traverse?

The authors determine the variation of the pitot-tube coefficient with angularity, and show in Fig. 3 of the paper that the minimum coefficient of the pitot tube is 0.97 with an angularity of 30 deg. Do angular flow and turbulence produce the same effect on a pitot tube? S. L. Kerr has shown[3] that turbulent flow may produce coefficients as low as 0.96 at 5 fps and still smaller at lower velocities.

The writer realized that the authors very carefully calibrated the pitot tubes used at the Little Falls Plant and obtained a coefficient of 0.97. May it not be somewhat different for other installations where it will not be possible to make this calibration?

In Fig. 4 of this discussion the writer shows a curve of discharge against gate opening obtained by the multiple pitot-tube method on three tests of the same turbine. Curves $B$ and $C$ are tests of the same runner at different heads. Curve $D$ is a test on a cast-iron runner of the same design as the one for $B$ and $C$ which was built with plate-steel buckets. Curve A is calculated from the laboratory test on a runner homologous to $B$ and $C$ runner. It would be rather remarkable if the discharge coefficient of a runner in the field were 25 per cent larger than for its prototype in the laboratory as it is indicated at 0.70 gate. It is unbelievable that a cast-iron runner would show 33 per cent more discharge than its prototype of plate steel. And yet the tests indicate approximately this increase at one part of the curve. The pitot tubes for this test were located 8 ft downstream from the intake, which location was very poor. There was undoubtedly considerable turbulence at the point of measurement which accounts for the erratic results.

Does this not indicate the danger of using this method without the required length of straight penstock ahead of the pitot tubes as recommended by the A.S.M.E. Test Code for Hydraulic Power Plants?

Henri Deglon.[15] The method presented by the author for computing piezometer and pitot-tube readings is subject to the following remarks.

1 The true pressure, in a bend at points where pitot-tube readings are made, is different from the mean pressure.

2 Subtracting the mean pressure from the piezometer readings gives velocity heads and consequently velocity distribution different from the true distribution.

3 The method employed checks for the example given with a coefficient of 0.97.

4 The mean velocity computed from the mean of the velocity heads is different from the mean velocity computed from the mean of the velocities.

The pressure distribution in the cross section of a pipe or a canal must be known to use the photoflow method for field test.

Regardless of the velocity distribution, the sum of pressure head plus location head is constant in a straight pipe or canal as shown by the Helmoltz theory.[16]

The uneven distribution of the velocities in straight pipes is caused by (1) disturbances originating at the intake (if not properly designed) or at bends and (2) by wall friction which creates local suppression and motion of particles from the periphery toward the center and from the center toward the periphery.

It is justifiable to use a mean pressure in the cross section of a straight pipe. However, great care should be taken to measure the pressure correctly, using at least three peizometers to detect angular flow at the piezometer location caused by disturbed flow, which causes the piezometer to over- or underregister.

Generally, the photoflow method will be used to measure discharge. If such is the purpose of the test it can be fulfilled without a velocity-distribution calculation. The mean velocity calculated from the mean of the velocity heads can be corrected with a pitot-tube coefficient smaller than the one used by the authors when the mean of the velocities is calculated.

The writer suggests that (1) it be determined which method with a constant correcting factor gives the most accurate results and (2) to check if the pitot-tube coefficient of 0.97 found in the case of a measurement made in a bend is the correct one to use in straight pipe.

The writer has found that a pitot-tube coefficient of 0.957 must be used if the mean of the velocity head is used.

However, the writer has not been able to determine which method of computing is the best because he has been unable to check them by measuring the water volumetrically.

D. W. Proebstel.[17] The photoflow method is of interest to the writer not only because he is the originator of it, but because it is a strong plea for recognition of a sound method in hydraulics testing, that is, the recognition of the pitot tube as a means for measuring the flow of water through closed conduits. This method

[13] Hydraulic Engineer, S. Morgan Smith Company, York, Pa.

[14] "Piezometer Investigation," by C. M. Allen and L. J. Hooper, Trans. A.S.M.E., vol. 54, 1932, paper HYD-54-1.

[15] Hydraulic Engineer, S. Morgan Smith Company, York, Pa.

[16] "Vorlesungen über Wasserkraftmaschinen," by R. Camerer, W. Engelmann, Leipzig, Germany, 1914, p. 64.

[17] Imperial Irrigation District, Imperial, Calif.

with its multiple pitot and piezometer tubes with readings taken by a camera eliminates personal error and practically all of the former objections to the use of the pitot tube.

The experiments conducted by the authors with streamline flow and the effect of angularity upon the pitot-tube coefficients is very interesting. From the many tests which the writer has conducted using the photoflow method he has observed that the velocity of the water within the closed conduit increases very rapidly from the inner surface toward the center. At a very short distance from the inner surface the velocity of the water changes but slightly until the other side of the conduit is approached where it drops rapidly. This would lead one to conclude that the greatest effect of angularity of flow is nearest the surface where there is the least flow of water. The pitot tubes placed in the main portion of flow would operate at coefficients approaching unity.

One of the outstanding features of interest in the tests on the Little Falls units was the unique arrangement of pitot and piezometer tubes. This arrangement was made to overcome the poor testing conditions due to conduit design. Had the conduit been straight and long the pitot tubes might have been placed on two diameters spaced 90 deg instead of on three diameters spaced at 60 deg.

The results obtained by the use of six piezometer tubes demonstrated that much care should be taken in placing them in the conduit. Placing them in pairs in horizontal positions is a safe arrangement. The writer has found, however, that with long straight conduits the readings of the piezometer tubes would be approximately the same whether four were used spaced 90 deg apart or three spaced at 120 deg. In the writer's opinion, this would indicate that the centrifugal action referred to in the paper is most noticeable in curved or irregularly shaped conduits. The change of velocity from the sides to the center in straight conduits is uniform and causes little or no centrifugal effect, or rather, balanced centrifugal action. The paper, perhaps, should have read, centrifugal force produced by an *irregular* change of direction of the path of the water."

The consistency of the results shown by gate-opening curves in Fig. 9 of the paper and the close agreement of check readings shown in Table 3 of the paper would seem to demand a very favorable recognition of the merits of the photoflow method.

### Authors' Closure

The paper on the photoflow method of water measurement has resulted in so much discussion that this closure can touch only upon some of the fundamental questions involved.

Current meters are outside of the scope of the paper and will not be considered in this closure, although a large part of some of the discussions pertained to them.

One of the important features mentioned in nearly all of the discussions was the value of the pitot-tube coefficient for angular flow. F. H. Rogers shows the theory on which this coefficient is based and shows the remarkable manner in which actual test results confirm his theory. Dr. W. F. Durand approaches the subject from the viewpoint of fluid mechanics and agrees with Rogers' theory, but also points out that the coefficient at angular flow can be materially affected by the size and shape of the pitot tube.

This then answers F. Nagler's question as to the discrepancy in the coefficient at 30 deg of pitot tube *C* of Fig. 1 of the paper as compared to those shown in Fig. 3. Mr. Nagler is in error when he states that these tubes are alike. Tube *C* of Fig. 1 is sharp edged, having no surface of revolution or flat plate on which the water may impinge. Therefore, as this tube is turned at an angle to the flow, the reaction is different from that for the tubes of Fig. 3, which do have surfaces of revolution.

Prof. W. S. Pardoe, in his criticism of the use of a 12-in. diameter pipe for determining the pitot-tube coefficient at various angles to the flow, was apparently somewhat confused as to the effect of a reduced velocity 2 in. away from the center line of the pipe. Any reduction in velocity away from the center would have the effect of increasing the apparent pitot-tube coefficient instead of reducing it as he has stated. In fact this very consideration may be the reason for the higher coefficients he obtained while rotating a pitot tube in a still smaller-diameter pipe, namely, 7 in.

The authors did not base their conclusions as to the pitot-tube coefficient at angular flow entirely on their test made in the 12-in. diameter pipe but took into consideration a large number of tests, some of which, like those by F. H. Rogers in 1910, were made under ideal conditions. Another general subject of discussion was the amount of angularity of flow that might be encountered in conduits. While it is possible that the angle of flow in small-diameter pipes such as are found in city mains is limited to 6 deg as stated by E. S. Cole, there certainly is no evidence that this is true for the larger-diameter penstocks to be found at power plants. In fact, certain tests seem to indicate that greater angularity exists. Such excellent researches as those by Prof. C. M. Allen on the distribution of salt as it intermingles with the flow of water in a conduit, being a case in point. Since tests showing the exact angularity of flow have always been made on small-diameter pipes, it is entirely possible that the flow in the larger-diameter pipes may be entirely different and actually have larger angularity.

We now arrive at the most important feature of the photoflow method, namely, the pitot-tube coefficient. Most of the pitot-tube calibrations have been made in small-diameter pipes and have indicated a coefficient close to unity. The authors have rated pitot tubes in pipes up to 12 in. in diameter and found the coefficient to be practically unity. However, there seems to be considerable evidence supporting a lower coefficient for the larger-diameter pipes encountered at power plants. It is quite possible that there is a difference in the character of flow of a small-diameter pipe as compared to a large pipe which would account for such a difference in the coefficient.

F. Nagler questions the possibility of a pitot tube ever having a coefficient of 0.970 when its angular-flow coefficient does not fall below this value. S. L. Kerr's paper mentioned by F. H. Rogers indicates that a design of pitot tube very similar to the designs shown in Fig. 3 of the paper had a coefficient of 0.934 in turbulent flow. This means that in turbulent flow the coefficient may be lower than any angular coefficient. This was also indicated by the test at Little Falls where the coefficient at a turbulent-flow section was found to be close to 0.97, whereas the minimum angular-flow coefficient of the pitot tube used was 0.971.

L. J. Hooper mentions a calibration of a pitot tube in a 36 $\times$ 16-in. venturi throat and in a 12-in. line. The flow conditions in the throat of a venturi meter can hardly be called disturbed flow, and if the flow in the 12-in. line did not have an angularity of more than 3 deg, the coefficients should have checked exactly. This is apparent from Fig. 1 of the paper which shows that the pitot-tube coefficient for an angularity of 3 deg is practically unity.

On the other hand, the series of tests at the Tulane Hydraulic Laboratory as mentioned in the discussion by Prof. W. B. Gregory, show an average pitot-tube coefficient of 0.976 in a 10-in. pipe.

Taking into consideration the independent calibrations of the pitot tube made on larger-size pipes, as well as all the foregoing discussion, the authors still advocate a pitot-tube coefficient of 0.976 for the larger-size pipes and penstocks used at power plants. That a large pipe may have a different coefficient from a small pipe is not at all unreasonable as is indicated by the

different coefficients necessary for the various sizes of venturi meters.

The discussions brought out some interesting arguments as to the accuracy of the photoflow method.

F. Nagler states that when a pitot tube is inserted in a cross section, the flow goes elsewhere. This is open to question since there is apparently very little reliable information on this point. L. J. Hooper also calls attention to the fact that a 1-in. pipe will affect the velocity 5 in. upstream.

However, a reduction or diversion of velocity in front of the pitot tube can be accomplished only by an increase in pressure at that point, and the pitot tube will measure this pressure plus the remaining velocity head. In this respect it differs from a current meter which will measure only the actual velocity.

J. D. Scoville takes exception to the accuracy of pressure measurements in disturbed flow. By measuring the pressure at the walls of the penstock with a long section of straight wall above and below the piezometers, such inaccuracies are eliminated. The measurement of pressures on a small surface injected into a large body of turbulent flow, however, is quite a problem and affects the accuracy of the type of pitot tube having self-contained pressure elements. Instruments of this type including the piezometer, are usually rated in comparatively small-diameter pipes under good flow conditions. As long as they are used in similar-size pipes, the results will be accurate, but when they are used either in the larger-diameter pipes or under disturbed flow conditions, considerable error may be introduced. This is especially true of the pitometer which has a coefficient of less than 0.90.

E. S. Cole bases the accuracy of tests with the pitometer somewhat on the ability to repeat tests. Repeated check tests, however, do not necessarily mean accurate absolute results especially where a coefficient differing considerably from unity has to be used.

J. D. Scoville questions the accuracy of the photoflow method because of the large discrepancy between some field test in which the photoflow method was used and model tests. This is hardly a fair criterion of the accuracy of any test method. The variations in discharge as shown in Fig. 4 of the discussion can just as readily be due to differences in runner castings and die forms as to a decrepancy in method of testing. We know of no other method of water measurement that has been discarded because in one isolated instance the discharge measurements of a turbine did not check the model-test results. Usually in such an event an investigation as to the runner step-up is made rather than blaming the methods of discharge measurement.

H. Deglon resurrects the old Bernoulli-theorem argument as to whether the sum of the velocity head plus pressure head is constant across a conduit. If it is, then very few tests or experiments have been made where the correct pressure of flowing water in a conduit has been determined. The pressure at the walls of the conduit where the velocity is low and where the piezometers are usually located, would then be quite different from the average pressure across the conduit. Without going into this question in detail, there certainly is sufficient experimental data available to show that the pressure across a conduit is constant except at elbows or bends where centrifugal force comes into play. Means for taking care of the latter condition have been considered in the original paper.

The remaining points brought out in the discussion relate to the advantages of the photoflow method of measurement.

One of the advantages claimed for the method is the short time required to obtain a complete reading. E. S. Cole states that the time of making pitometer traverses is misrepresented and claims 20 minutes is sufficient for a ten-point traverse. This allows 1 minute per reading per point and certainly does not cover the flow cycle. It is recognized by the majority of point-traverse advocates that in order to obtain accurate results, sufficient time must be allowed to read the pitot tubes and piezometers several times at each point; in fact, F. H. Rogers suggests five such readings. Under such conditions, an hour per traverse would be more according to the actual facts.

Several examples were cited where the pitot traverse gave consistent results. The tests mentioned were probably all made in long straight penstocks where the changing distribution of flow was undoubtedly small, and a careful traverse under such conditions should give fairly consistent results. However, this does not alter the fact that there is always a time variation of velocity of flow as brought out in the discussion by Dr. W. F. Durand. L. F. Moody also calls attention to the fact that reliable results with the traverse method can only be obtained at an expenditure of considerable time and labor and that a single reading of the tube at each point is not sufficient. The disadvantages of extending the time on test are well summarized in the discussion by L. F. Moody.

J. F. Roberts' objection to the photoflow method because of the time of shutdown required seems to be rather far fetched. It should be realized that this method is advocated primarily for the large-size conduits found at power plants. Here a pitot-tube traverse is not the simple proposition of sticking a pipe into the penstock. Some sort of support for the pitot-tube pipe inside the penstock must be provided and will, therefore, require a shutdown. If the output of the plant is too valuable to permit a 6- to 8-hour interruption of one unit, there are always a number of approximate methods that can be used to determine the discharge.

In conclusion the authors wish to express the thought that any section that is suitable for measurement by pitot-tube traverses is equally suitable for the photoflow method, with a greater degree of accuracy.

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